A CLASS BOOK OF BOTANY

ERNEST STENHOUSE

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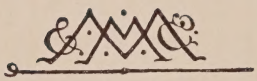

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A CLASS BOOK
OF
BOTANY

BY

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PREFACE

THE present course of botany has been drawn up primarily for the use of students preparing for University Matriculation, School Certificate, Senior Local, and other examinations of similar standard. It is hoped, however, that it will also prove useful to members of field clubs and other amateurs interested in living plants and their doings.

In accordance with modern views on the teaching of elementary botany, the book is concerned with the life-histories, activities and general behaviour of plants rather than with their structure ; in fact, details of structure are introduced only so far as they are necessary for the understanding of the vital processes considered. The earlier chapters deal with the conditions of healthy existence of individual plants of different "life forms." They naturally lead to a description—fuller than is usual in books of this character—of the plant communities of meadows, ponds, hedges, woods, heaths and other easily accessible habitats. It is hoped that this account will form a guide to profitable field excursions and an introduction to a side of botany which, perhaps more than any other, gives comprehensive views of the subject. In the chapters on reproduction and classification, seventeen common families of flowering plants are studied with special attention to floral mechanism, and the opportunity is taken to explain the use of a Flora. Sections on British trees, some common flowerless plants, and simple work with the microscope have been included to meet special needs.

The method of presentation adopted is one which the author,

in a long experience as teacher and examiner, has found specially helpful to students at this stage of their work. Throughout the course, description and discussion are kept in close association with observation and experiment. In arranging the scheme of practical work, care has been taken to include only exercises which are of real significance and can be carried out with simple apparatus ; and whenever possible, so to frame the instructions for their performance that the student is led to investigate some problem for himself. The training in scientific habits of thought, afforded by certain easy experiments in plant physiology and the interpretation of the results obtained, is of exceptionally high educational value.

Since students of botany, more than of other subjects, are dependent on the seasons for their material, it is not supposed that anyone will attempt to work through the book in the order of the chapters. The monthly calendar given at the end will serve as a reminder of some of the more obvious current events in the British plant world, and, with the schemes of study for the four seasons, will indicate what work can be usefully undertaken at the time. The numerous cross references, with the glossary and very full index, should make it easy for the student to seize opportunities as they arise.

The bearing of botany on practical agriculture and horticulture has been kept in mind constantly, and the plants recommended for study are all well known, and most are of economic importance as weeds, crops or timber. Alternative types are described in cases where any difficulty in obtaining specimens seems possible.

The illustrations—among them a large selection of photographs taken in the field—are unusually numerous and varied, and many have been prepared expressly for the book.

Some hundreds of recent examination questions are included, by special permission of the University of London, the Joint Matriculation Board of the Universities of Manchester, Liverpool,

Leeds, Sheffield and Birmingham, the Delegates to the Oxford University Local Examinations, the Syndicate of the Cambridge University Local Examinations, the Controller of H.M. Stationery Office, and other authorities. The questions are so classified as to form summaries, useful for revision, of the chapters to which they are appended. Their source is indicated by the following contractions: Cert., Teachers' Certificate of the Board of Education; C.H.L., Cambridge Higher Local; C.J., Cambridge Junior; C.P., Cambridge Preliminary; C.S., Cambridge Senior; J.M.B., Joint Matriculation Board; L.M., London Matriculation; Prel. Cert., Preliminary Examination for the Teachers' Certificate of the Board of Education; N.F.U., National Froebel Union; O.J., Oxford Junior; O.S., Oxford Senior.

The author is indebted to Sir Richard Gregory for much kindly help and valuable advice during the preparation of the book, and to Mr. A. J. V. Gale, M.A., for assistance in reading the proofs.

E. STENHOUSE.

Boars Hill,
Oxford, *May* 1925.

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PART I.

NUTRITION AND GROWTH.

CHAPTER I.

SEEDS.

1. SEEDS OF TYPICAL DICOTYLEDONS.

PRACTICAL.

1. Fruit of Sycamore.—(*a*) Draw in outline from nature a well-formed sycamore fruit in position on the twig, showing the method of attachment of the fruitlets—called *samaras* (Fig. 1)—to each other and to the twig. Notice the position of the seed-case of each. Try if the samaras are readily detached from the twig by a slight pull. Drop at the same moment from a height (*e.g.* the top of a staircase) a complete samara and one deprived of the "wing," and compare the times of falling. Describe any peculiarities in the motion of the falling samara. What would be the effect of a strong wind on it? Suggest how the wing may be useful to the seed contained in the samara.

Open the seed-box (*pericarp*) at the thick end of the samara, and draw the *seed* in position inside, showing the mode of attachment of the seed to the pericarp, and the layer of hairs between pericarp and seed.

(*b*) *Sycamore seed.*—Remove the seed from a samara which has been soaked in water for 48 hours and examine it. Take off the thin *seed-coat* and carefully uncoil the contained *embryo*; notice its green colour, and identify its parts (two cotyledons, a radicle and a plumule) by comparison with Fig. 3. Draw these parts in outline, twice natural size, and indicate the scale on the drawing by "× 2." Make a plasticine model of the embryo

(×4), and fold up the model as nearly as possible in the manner of folding of the embryo : *i.e.* place the cotyledons face to face, fold them in the middle and roll them up. Wrap the model embryo in tissue paper (representing the seed-coat).

(*c*) With a sharp razor cut through a soaked samara in the plane of the wing, and draw the section of the embryo, seed-coat and pericarp in position (×6). Name all the parts.

2. Fruit of sunflower.—(*a*) Examine so-called sunflower "seeds" as supplied by florists. Each is really a fruit, and the seed itself cannot be seen until the shell (pericarp) is broken open. Remove the seed from the pericarp, and in the seed make out and examine the seed coat and embryo (consisting of two cotyledons, a radicle and a plumule). Make a plasticine model of the embryo (×6), with the parts arranged naturally. Compare the arrangement of the cotyledons in sycamore and sunflower embryos. Which, if any, part of the sunflower embryo is swollen, as compared with the sycamore embryo ?

(*b*) With a sharp knife or razor make a section along the length of a good sunflower fruit, so as to divide each of the sides in half. Draw the cut surface (×6), showing and naming on the drawing the pericarp, seed coat, cotyledons, plumule and radicle.

(*c*) Remove the seeds from a dozen sunflower fruits, pound them in a dry mortar, and then put them, on a sheet of white paper, into a hot oven for a quarter of an hour. What sign can you then see that *sunflower seeds contain oil* ?

3. The melon or vegetable marrow seed.—Notice the peculiar shape (somewhat like a pocket-flask) of the seed, and the thickened margin. Carefully cut the seed-coat away so as not to injure the part inside. How many cotyledons are present ? What is their colour ? Can you see the plumule and radicle clearly ? If not, do not decide that they are absent, but leave the question to be settled later, when you watch a vegetable marrow or melon seed "come up."

4. Seeds of bean and pea.—(*a*) Examine fruits (pods) of bean and pea and notice the manner of attachment of the seeds to the "shell" (pericarp) of the fruit. On the detached seed observe the scar (*hilum*) left by the stalk which attached it to the pericarp. Soak dry seeds in water and examine them at intervals, noticing the wrinkling of the seed coat as it enlarges by absorption of water, and the disappearance of the wrinkles later as the contained embryo becomes swollen by absorbed water. Wipe a soaked seed dry and then squeeze it ; a drop of water escapes from a little

hole (*micropyle*) in the seed coat close to one end of the hilum. Strip off the seed coat, noticing the funnel-shaped depression in it leading to the micropyle and covering the radicle. Wedge apart the two fleshy cotyledons and see the leafy plumule between them. Observe that the cotyledons are attached by very short stalks to the axis (radicle + plumule). Take off one cotyledon, and make a drawing of the inner face of the other cotyledon, with the adhering plumule and radicle.

Compare the shape and structure of the seeds of broad bean scarlet runner bean, and French or kidney bean.

(*b*) *Stored food present in the cotyledons.*—Scrape the surface of a bean or pea cotyledon and then pour on it a drop of iodine solution (p. 491). Is there any change? Pour also a drop of iodine solution on a piece of laundry *starch.* Is a similar blue colour formed? What substance appears to be present in the cotyledons?

Test crushed dry seeds, or some pea flour, for *oil* as in Expt. 2, *c* (p. 2). Is any appreciable quantity of oil present? Perform also Expts. *d* and *e* (p. 17).

5. Castor-oil seed—Notice the flattened egg-shape of the seed, the hard, prettily mottled seed coat, and the wart-like *aril* at one end. Remove the seed coat (noting that the aril is plainly an outgrowth of it) and pare down the edge of the contained white, oily mass of *endosperm* until it shows a split. Wedge open the split and see the parts of the embryo, viz.—two very thin, veined leaves (the cotyledons) lining the cavity in the endosperm, the peg-like radicle with its tip reaching the seed coat at the aril, and the small plumule. Draw (×4) the plumule, radicle and inner face of one cotyledon in position against the endosperm.

Cut a longitudinal section of another seed to bisect both cotyledons, as well as the plumule and radicle. Draw the section, four times natural size, and name all parts.

Crush the endosperm of one seed and test it for starch. Heat the crushed endosperm of another on a sheet of white paper in an oven. Is *oil* present? Contrast the *position* of the stored oil in sunflower and castor oil seeds.

6. Other dicotyledon seeds containing endosperm.—(*a*) *Buckwheat.* Carefully break open the shell (pericarp) of a soaked buckwheat grain (fruit), and remove the single seed. Dissect it (*i.e.* separate its parts) with mounted needles.* Repeat with

* Easily made by pushing the eye end of a sewing needle into the middle of a straight piece of fresh twig and allowing to dry.

several grains until you have a clear idea of the structure of the seed. Pick out the floury endosperm and test it with a drop of iodine solution.

(*b*) *Ash.* Open the thick end of a soaked ash samara to see the seed and its manner of attachment to the pericarp. Pare down the stiff almost woody material (endosperm), of which the bulk of the seed is composed, to find the small embryo in the middle, and identify the two cotyledons and the radicle.

(*c*) *Morning glory* (*Ipomaea*). Dissect seeds which have been soaked in water for several days and see the embryo, with crumpled cotyledons, embedded in slimy endosperm.

The scope of botany.—The study of living things is called biology; it has two main divisions, because living things are of two kinds, animals and plants. Botany is the branch of biology which deals with plants; zoology is the study of animals.

Botany, then, is concerned with all that relates to the forms, activities and distribution of plants. Evidently its scope is very wide, for plants vary enormously in almost every respect. In size they range from kinds which are invisible without the help of a powerful microscope, to such giants as the " big trees " of California, which may reach a height of 300 feet. In construction also, plants differ to an almost inconceivable extent, so that in every kind of climate and in almost every kind of situation plants are to be found, fitted by appropriate peculiarities to live under their special conditions.

A plant, like an animal, passes through the stages of infancy, youth and maturity, and sooner or later dies. Evidently each kind of plant must have some means of forming new individuals to take the place of those which perish, or its race would become extinct. This process of making new young plants is called **reproduction**; it is carried out in different ways by various races of plants; but among the best-known plants it is accomplished by the formation of **seeds**, which are produced by parts known as flowers.

In this book we shall be concerned almost entirely with such plants as reproduce by means of seeds. They are called **seed-bearing plants**, or flowering plants, to distinguish them from

ferns, mosses, seaweeds and the like (Chap. XXI.), which do not form flowers or seeds.

A healthy seed, in the ground under favourable conditions, sprouts, and presently becomes a full-grown plant like its parent or parents, with the power of producing seeds in its turn. Thus the complete life-history of a flowering plant is comprised in the cycle from a seed of one generation to the seeds of the next, and it will be well in our study of plants to adopt this natural order of events. We shall begin, therefore, by examining a number of typical seeds.

Fruit and seed.—Those parts of a plant which contain ripe seeds are called fruits ; each fruit is the final stage of a flower. It will be a help to clear thinking if we use the word **fruit** for what remains of one flower when the seeds are ripe, and in no other sense. Thus, each pod of a bean or pea plant is one fruit, since it is the remains of one flower. It consists of a " shell " (called the **pericarp**) and the contained **seeds** (commonly known simply as " beans " or " peas.") At the stalk-end of the pod may be seen several small, green leaves ; since these were originally parts of the flower, they also must be regarded as part of the fruit.

The bean or pea fruit contains several seeds, but the fruits of many other plants contain only one seed each, which almost or entirely fills the pericarp. Thus, an acorn, which is the fruit of the oak, contains only one large seed inside its somewhat woody pericarp. Similarly, what are sold by seedsmen as sunflower seeds, are really fruits ; the outer layer of each is the pericarp, and the seed cannot be seen until the pericarp is broken open. Again, a grain of maize or of wheat is not merely a seed ; it is an entire fruit, since the outer layer is the pericarp. In this case, however, the seed coat and pericarp cannot be separated.

FIG. 1.—Two Sycamore fruits, each consisting of two samaras.

The fruit and seed of the sycamore.—Each flower of a sycamore tree is usually succeeded in the autumn by a fruit like those shown in Fig. 1. It consists of two similar parts, which are

called **samaras**. Sometimes a sycamore fruit consists of three, or even four, samaras.

At one end of the samara the pericarp forms a rounded case containing the seed. The rest of the pericarp is a flattened plate, called the *wing*.

The samaras of the sycamore are somewhat firmly attached to the twigs of the tree, and are only detached by fairly strong winds, so that they are likely to be blown to some little distance from the tree before they reach the ground.

The wing considerably increases the surface of the samara without adding much to its weight, so that even in still air it would fall much more slowly than a samara without wing. Moreover, the wing is not truly flat, but is slightly twisted, and on that account the samara spins as it falls through the air. The spinning motion further delays the samara in the air and gives it time to be blown to a greater distance. In addition, the spin perhaps tends to screw the seed case slightly into the ground if it falls on a soft surface.

The question of seed dispersion will be considered at length in Chap. XVIII., but many of its advantages to the future plants are quite obvious. Being scattered far and wide, the seeds do not deprive each other of room and soil-moisture, nor are they overshadowed by the parent plant. Although many of the seeds may fall "on stony ground" or in other unfavourable situations, it is plain that a larger proportion will have a chance of growth than if they all fell from the twig straight to the ground beneath, as in Fig. 359.

When the pericarp of the sycamore samara is cut open* it is found to be lined with fine hairs (Fig. 2, *h*.), embedded in which is a **seed**, about the size of a small pea. The layer of hair helps to keep the seed dry, and no doubt often protects it from harm in other ways as well. The outer part of the seed is a thin brown skin, called the **seed coat**; the rest of the seed consists of an undeveloped sycamore plant. Such a young plant, present in a seed, is known as an **embryo**. When the brown seed coat, which covers it closely, is carefully peeled off, the sycamore

* Samaras, if dry, should be soaked in water for two days before dissection.

embryo is revealed as a green object rolled up to form a ball. On being unrolled it is seen to consist of a rod, perhaps half an inch in length, bearing near one end two strap-like leaves, each

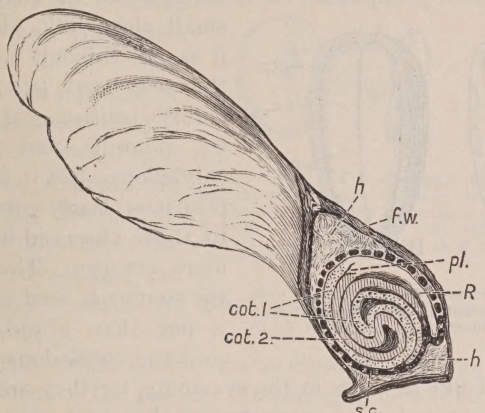


FIG. 2.—One Sycamore Samara, cut through in the plane of the wing. *s.c.*, seed coat, indicated by a thick, broken line; *f.w.*, pericarp; *h.*, lining of hair; *R.*, radicle; *pl.*, plumule; *cot.* 1, *cot.* 2, cotyledons, diagrammatically shaded. (× 2.)

of which is about an inch long. The leaves are called **cotyledons**. The rod, which is in the middle line of the embryo, consists of two very unequal parts, on opposite sides of the cotyledons: the greater portion of the rod is called the **radicle**; the smaller part is a tiny bud, seen when the cotyledons are carefully pulled apart, and called the **plumule**. The relative positions of these parts are shown diagrammatically in Fig. 3.

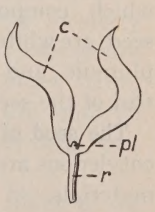


FIG. 3.—Diagram of Sycamore embryo, uncoiled. *pl.*, plumule; *r.*, radicle; *c.*, cotyledons. (× 1.)

When the sycamore seed grows (p. 33), the cotyledons act as the leaves of the young plant until the first foliage leaves (already present in a simple form in the plumule-bud) can unfold and begin work; the plumule also forms nearly all the stem, while the lower part of the radicle gives rise to the main root and its branches. Even in the seed, therefore, the principal regions of the future tree are already recognisable.

The seed of the sunflower.—As has been mentioned on p. 5, the so-called seed of the sunflower (Fig. 4) is really a fruit, the outer case or shell (*pcp.*) being the pericarp. When this is broken open the seed is exposed; it is attached to the pericarp by a small, thin stalk. In the seed it is not difficult to recognise the seed coat (*s.c.*), and the embryo consisting of the radicle (*r*), plumule and two oval cotyledons (*cot.*) in relative positions clearly corresponding to those observed in the sycamore embryo. The radicle of the sunflower seed is more like a peg than a rod, however; and the cotyledons are not so clearly leaf-like as those in the sycamore, for they are not green and thin, but pale and somewhat swollen with material easily proved (Expt. 2, *c*, p. 2) to contain oil. Oil is extracted by pressure from sunflower seeds, and in some countries is used instead of butter.

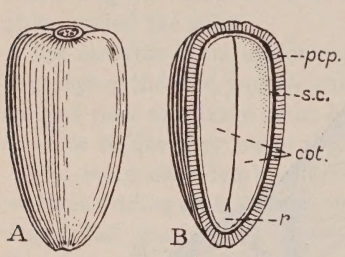


FIG. 4.—Sunflower fruit. *A*, entire; *B*, cut in half lengthwise. *pcp.*, pericarp; *s.c.*, seed-coat; *r.*, radicle; *cot.*, cotyledons. (× 2.) (After Baillon.)

The seed of the melon.—The seed of the melon, or of the closely related vegetable marrow, is flattened, and of pointed oval shape (Fig. 5). The border of the seed coat is thickened. The two cotyledons, which compose the greater part of the seed, are white and only slightly fleshy. The plumule and radicle are at the pointed end of the seed and are difficult to see.

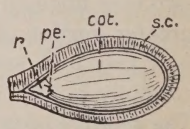


FIG. 5.—Melon seed cut open, and with one cotyledon removed. *s.c.*, seed-coat; *pe.*, plumule; *r.*, radicle; *cot.*, inner face of remaining cotyledon. (× 1.) (After Baillon.)

The seed of a bean.—In a bean seed the cotyledons are even more swollen with food materials—in this case largely starch (Expt. 4, *b*, p. 3)—than the oily cotyledons of the sunflower seed, and are therefore still less suggestive of leaves in appearance. They form two fleshy lobes, which compose the bulk of the embryo, and are closely covered by the seed coat; the peg-like radicle protrudes from between them (Fig. 6). Where it covers the radicle, the seed coat forms a funnel-shaped pocket, which

opens to the exterior by a small hole, the **micropyle**. Such a perforation of the seed coat over the tip of the radicle occurs in seeds generally, but is usually most conspicuous in the largest seeds; it is very distinct in French beans and runner beans. The radicle is continued into the plumule or stem bud, which lies between the bases of the two cotyledons. Several young leaves are very clearly distinguishable in the bud. As in the seeds previously studied, the cotyledons are attached by short stalks between the plumule and the radicle.

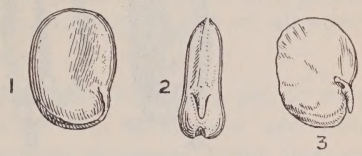


FIG. 6.—Seed of Broad Bean. ($\times \frac{1}{2}$). 1, seen fron the side. 2, seen edgewise; the conical ridge on the seed coat shows the position of the radicle beneath. In 3, the seed coat and the nearer cotyledon are removed to show the plumule. (After Thompson.)

The distortion of the cotyledons by stored food is more marked still in the seeds of the **pea** and the **oak**, although their position shows them to be the equivalents of the leaf-like cotyledons of the sycamore. In these seeds, as in bean seeds, the food is largely starch.

Albuminous and exalbuminous seeds.—The seeds described hitherto consist entirely of seed coat and embryo. Any food present in them is stored in some part of the embryo, usually in the cotyledons. In a large number of seeds, however, the seed coat is not entirely filled by the embryo, but it also contains—*outside the embryo*—a store of food. Such food was formerly called albumin, and seeds containing *food outside the embryo* are still often called **albuminous** seeds. Seeds, on the other hand, which do not contain a store of food outside the embryo are described as **exalbuminous**. Sycamore, sunflower, bean, pea and oak seeds are all exalbuminous.

The castor-oil seed.—The seed of the castor-oil plant is an excellent example of an albuminous seed. Its structure is well shown in Fig. 7. The embryo—consisting of plumule, radicle and two cotyledons occupying the usual relative positions—lies in the middle of the seed. Between it and the hard shell-like seed coat, however, is an oily mass of cheesy consistency called the **endosperm**, which is used as food by the young plant in its

early stages of growth. It is noticeable that the thin cotyledons are in very close contact with the endosperm; the

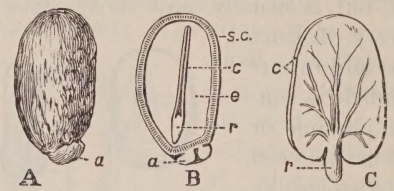


FIG. 7.—Castor-oil Seed. *A*, external appearance; *B*, in longitudinal section; *C*, embryo removed from endosperm and seen from the side. *a.*, aril; *c.*, cotyledons; *e.*, endosperm; *r.*, radicle; *s.c.*, seed coat. (*A*, *B* × 1; *C* × 1½.) (After Baillon.)

minute plumule lies between the cotyledons; the radicle reaches to the seed coat at one end of the seed, and at this end there is a wart-like spongy outgrowth of the seed coat called an **aril**.*

Other albuminous seeds with two cotyledons.—Of the seeds which are large enough for easy dissection by beginners, not very many of those with two cotyledons possess stored food outside the

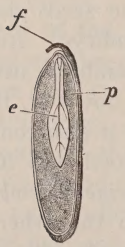


FIG. 8.—Longitudinal section of seed of Ash. (× 2.) *e.*, embryo; *f.*, stalk; *p.*, endosperm. (After Avebury.)

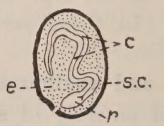


FIG. 9.—Morning Glory seed cut in half vertically. *s.c.*, seed-coat; *r.*, radicle; *c.*, cotyledons; *e.*, endosperm. (× 1.) (After Sargent.)

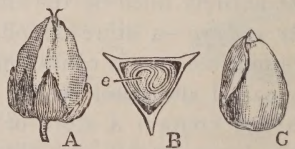


FIG. 10.—Buckwheat. *A*, fruit (× 4); *B*, the same cut across, showing the embryo surrounded by the endosperm, *e.*; *C*, embryo removed from the seed and viewed from the side. (After Baillon.)

embryo. The seeds not only of the castor-oil plant but also of ash, morning glory (*Ipomaea*) and buckwheat, contain such "outside" food in a form easily recognised, and repay examination. In the ash seed (Fig. 8) the endosperm is chiefly

* The term "aril" is given to any structure which grows on the seed coat during the ripening of the seed.

cellulose (p. 19); in the **morning glory** (Fig. 9) it is mainly *gum*, which lies between the seed coat and the crumpled embryo; and in the **buckwheat** (Fig. 10) it is floury and so nutritious that it is extensively used as human food, a fact which perhaps accounts for the name, though the plant is not at all closely related to true wheat.

Dicotyledons and monocotyledons.—Flowering plants which in the embryo stage possess two cotyledons are called dicotyledons. Thus, the sycamore, sunflower, beans, pea, oak, castor-oil plant and buckwheat are all included in the **dicotyledon** group, or **class**, of flowering plants. The seeds of most dicotyledons are exalbuminous, although in that case they contain more or less stored food in some part of the embryo.

Flowering plants which in the embryo stage possess only one cotyledon are also common. They are grouped by botanists in the **class monocotyledons**. It will be seen later that dicotyledons and monocotyledons constantly differ from each other in various other respects as well as in the number of cotyledons present in their embryos, so that there are good reasons for separating them so widely in the classification of plants. One or two monocotyledon seeds must next be studied.

2. SEEDS OF TYPICAL MONOCOTYLEDONS.

PRACTICAL.

1. Maize fruit.—A maize grain is a one-seeded fruit. Soak large grains ("Horsetooth" maize is better for dissection than ordinary Indian corn) in water for three days. Notice the shape of the grain, and the whitish oval patch on one side; this marks the position of the embryo. Draw this side of the grain (×4). Peel off the skin (=pericarp + seed coat) of this side, and observe the plumule (towards the rounded end of the grain) and radicle (towards the pointed end), with the single shield-like cotyledon behind (towards the interior of the grain) and curling round the sides of the plumule and radicle. Pick out the whole embryo and study it. Separate the leaves of the plumule with a needle and expose the radicle in its sheath.

Make a longitudinal section of another grain to bisect the embryo. Cover one cut surface with iodine solution. What is

the colour of the embryo ? The part of the grain which turns blue-black is endosperm ; what food does it contain ? Compare the appearance of the cut surface not treated with iodine. Draw one cut surface (×4) and name all parts.

Make a cross-section of another grain at the level of the plumule, draw and name all the parts.

2. The wheat grain.—A grain of wheat is also a one-seeded fruit. Examine grains soaked in water over-night. Notice the groove along one side, and—on the opposite side near one end—the round white patch marking the position of the embryo. At the other end is a tuft of very fine hairs. Cut a longitudinal section bisecting the embryo, and draw the section (×8). Cover the cut surface with iodine solution ; describe and explain any colouration produced.

Grains of maize and wheat.—A grain of maize or wheat is a *one-seeded fruit.* In other words, the grain includes not only the seed, but also the pericarp. In this respect it resembles the samaras of the sycamore and ash, and the fruits of the sunflower and buckwheat. When, however, a grain of maize or wheat is carefully examined, it is seen to differ greatly from all the fruits hitherto considered.

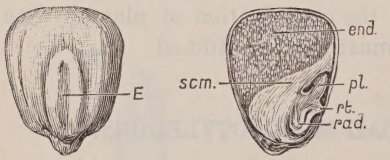


FIG. 11.—A Maize Grain, *A*, in surface view ; *B*, in longitudinal section, through the middle line of the embryo. *E*, position of embryo ; *end.*, endosperm ; *pl.*, plumule ; *rad.*, radicle ; *rt.*, origin of a root ; *scm.*, scutellum (cotyledon). (×2.)

A **maize grain** is somewhat flattened, and rather pointed at one end (Fig. 11). On one flat side, near the pointed end, may be seen a whitish patch which marks the position of the **embryo**, and along the middle line of this a ridge caused by the axis (plumule and radicle) of the embryo.

When the grain is cut through lengthwise with a sharp knife, in a direction which cuts the axis down the middle, the *single cotyledon* may be seen. It is a curled plate lying between the axis of the embryo and the middle of the seed, and in close contact with a mass of **endosperm** which forms the greater portion of the seed. This food material at once turns blue when a drop

of iodine solution is placed upon the cut surface, showing that it contains a considerable amount of starch. The embryo contains a little oil. The young leaves of the plumule or stem-bud may be distinguished without difficulty in the section. The tip of the radicle, covered by a sheath, is near the pointed end of the grain.

A **wheat grain** (Fig. 25) is egg-shaped, with a deep groove running down one side. One end is clothed with a tuft of very fine hairs; * near the other end, on the side opposite to the groove, is a raised area, beneath which is the embryo. When the wheat grain is examined in longitudinal section (Fig. 26) its structure is seen to correspond closely to that of the maize grain. The greater part of the seed is again quite outside the embryo, and consists of a mass of starchy endosperm. It is the endosperm which is made into flour when wheat is ground. The single cotyledon (scutellum) is plate-like, and lies in close contact with the base of the endosperm.

Maize and wheat are grasses, and, like all grasses, belong to the **monocotyledon class** of flowering plants. Other plants of this class are the sedges, the rushes, lilies (p. 411), the daffodil and snowdrop (p. 413), the iris and crocus (p. 415), the orchids, and their relatives among British plants; besides palms, etc. Most monocotyledons have albuminous seeds; some, however, are exalbuminous, that is, have no stored food in their seeds apart from that contained in the embryo.

The relationships of the fruit and its contents are concisely shown in the following table:

- Fruit
  - Pericarp
  - Seed(s)
    - Seed coat
    - Endosperm (not always present in ripe seeds)
    - Embryo
      - Plumule
      - Cotyledon(s)
      - Radicle.

* The remains of the stigmas of the flower (p. 419).

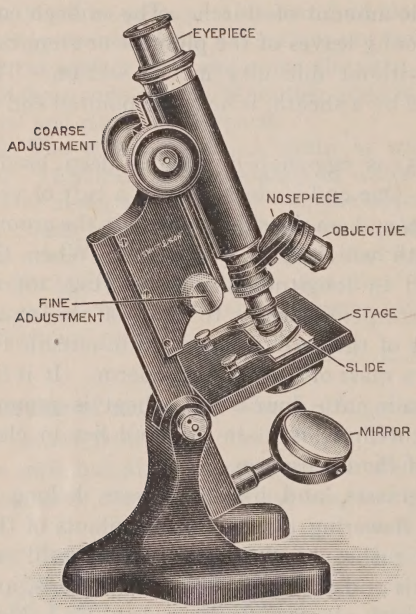


FIG. 11*a*.

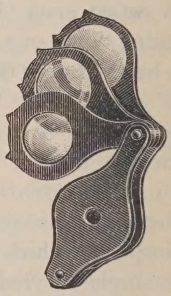


FIG. 11*b*.

FIG. 11*a*.—A typical student's microscope (Swift's "Didaxis"). By means of the hinge above the foot, the tube carrying eye-piece and objective can be turned at any inclination. For the examination of objects mounted in liquid it should be vertical, and the stage consequently horizontal. The nose-piece allows either of the objectives shown to be turned quickly to fit on the lower end of the tube, and thus saves time in changing. The object to be examined—supported on a glass slide (3 in. × 1 in.) and covered with a thin cover-slip—is placed in the centre of the stage and illuminated by light reflected from the mirror through the hole in the stage. One side of the mirror is plane; the other, for use with the high-power objective, is concave. The lighting is regulated by a diaphragm under the stage. The low power should always be used first, the tube being raised or lowered by means of the coarse adjustment until the object can be seen clearly. The fine adjustment is used for exact focussing, especially with the high power.

FIG. 11*b*.—A triple pocket magnifier. The three lenses, of different magnifying powers, may be used separately or in combination, being held close to the eye to avoid distortion of the image. To leave both hands free for dissection, the magnifier may be supported at any desired height on a darning needle pushed through a cork fitting in the handle, the point of the needle being stuck into the cork of a small wide bottle serving as a stand.

*3. RECOGNITION AND PROPERTIES OF STORED PLANT FOODS.

PRACTICAL.

1. Starch.—Use laundry starch. (*a*) Pour a drop of iodine solution on to a piece of starch; the starch becomes blue-black.

(*b*) Shake up a small piece of starch in a large test tube nearly full of water, and allow to stand; the starch settles to the bottom. Filter the water, and test the filtrate with iodine solution; no blue colour is produced. Starch is therefore insoluble in cold water.

(*c*) Pour boiling water on the starch sediment obtained in (*b*). The starch swells up and disappears from sight. Add iodine solution to some of the hot liquid; no blue colour is formed. Cool the rest and add iodine solution; a blue colour is obtained. Repeat with a very small quantity of starch and convince yourself that the test is a very delicate one.

(*d*) To a drop of water on a microscope slide add just enough starch to make the water slightly milky. Cover with a clean cover-slip and examine, first with the low power of the microscope and then the high power. Draw about a dozen grains. With a glass rod place one drop of dilute iodine solution on the slide at the edge of the cover glass, and by touching the edge of the cover glass with blotting-paper at the opposite side, draw the iodine solution under the cover glass. Observe that the starch grains turn blue as the iodine reaches them.

Compare the size and shape of starch grains obtained from potato (by dipping a small piece of raw potato into a drop of water on a slide), wheat flour, maize endosperm, and rice.

2. Sugars.—(*a*) Add a particle of grape sugar to a quarter of a test-tubeful of freshly mixed Fehling's solution (p. 491), and put the tube in a vessel of boiling water. A brick-red precipitate is produced. Test in the same way some juice of a grape and other fruits, and scrapings from onion, carrot and beetroot.

(*b*) Repeat with a particle of cane sugar (table sugar). No precipitate is produced with Fehling's solution. Boil another small pinch of cane sugar with dilute hydrochloric acid for a few minutes; add this solution to Fehling's solution and heat; a brick-red precipitate is produced. Test in the same way any of the materials used in (*a*) which did not show the presence of grape sugar.

* This section may be postponed by junior students.

3. Cellulose.—Ordinary cotton wool is almost pure cellulose. Soak some cotton wool in iodine solution; it is stained a faint *yellow*. Soak another portion in sulphuric acid (concentrated acid diluted with an equal volume of water) and then in iodine solution; the cotton turns *blue*.

Break a date "stone" (seed) across the middle. Test one half with iodine solution; the seed turns yellow. Dip it in sulphuric acid; it turns blue. Dip the other half first in sulphuric acid and then in iodine solution, and observe the similar effect. What substance is abundant in the date seed?

Similarly test a shaving from the endosperm of an ash seed (p. 10).

4. Wood.—(*a*) Test a wooden match for starch and cellulose by dipping it first into iodine solution and then into sulphuric acid.

(*b*) Dip another wooden match into an acid solution of phloroglucin (p. 491); the wood turns *reddish-violet*. Test in the same way shavings from a date seed, a hazel-nut shell, an acorn shell and a plum stone.

5. Oils and Fats.—(*a*) Place separate small portions of crushed sunflower seeds, castor-oil seeds, Brazil-nut (seed), desiccated coconut, and ground almonds, on white paper in a hot oven for a few minutes. In each case a grease stain is produced on the paper.

(*b*) With a glass rod place a drop of osmic acid * on each grease stain; the stain is blackened. Compare the effect of osmic acid on an ungreased part of the paper. Mix a drop of olive oil or linseed oil with one of osmic acid on a white plate; note the blackening.

(*c*) Add 10 c.c. of petrol, ether, benzene or chloroform to a thimbleful of crushed oily seeds in a test tube, and cork the tube. **These liquids must not be used near a flame.** After half an hour pour off the liquid into a dish and place the dish in a draught until the ether or other solvent has evaporated; note the residue of oil left in the dish. Place a drop on paper and note the grease stain produced. Test with osmic acid. Oils are soluble in petrol, ether, benzene and chloroform. (Castor oil is exceptional in being soluble in alcohol also.)

6. Proteins.—An example of a protein is egg albumin (white of egg). Proteins, similar in many respects to egg albumin, occur

* 1 per cent. strength (to be obtained from dealers in microscope accessories). Another and cheaper test for oil is the aniline dye known as Sudan III. (p. 493); it turns oils red.

in all seeds and in various other parts of plants. Shake fresh white of egg with water and filter the mixture. Divide the filtrate into three parts.

(*a*) *Xanthoproteic test.*—Add a few drops of strong nitric acid ; a white precipitate of coagulated albumin is formed, which becomes *yellow* on warming. Pour off the acid and add ammonia solution to the precipitate ; the precipitate becomes *orange* coloured.

(*b*) *Millon's test.*—To another portion add Millon's reagent (p. 491) ; a white precipitate is formed, which becomes *red* on boiling.

(*c*) *Biuret test.*—To a third portion add caustic soda (or potash) solution, and then two or three drops of weak copper sulphate solution ; a *violet* colour is produced.

(*d*) Apply tests (*a*) and (*b*) to wheat flour, pea flour, and crushed Brazil nut from which the oil has been extracted with ether. In each case moisten the substance, in a dish, with (i) strong nitric acid and ammonia and (ii) Millon's reagent, and then gently heat in an oven.

(*e*) Put a teaspoonful of pea flour in each of two test tubes, and add to one 30 c.c. of water and to the other 30 c.c. of 10 per cent.* salt solution ; shake, allow to stand for several hours, and then filter each. Test the water extract for proteins. Pour the saline extract into a beakerful of water ; notice the separation of material evidently soluble in salt solution, but insoluble in water alone. Test the precipitate for proteins.

(*f*) The bulk of the protein in wheat flour is easily separated as a mixture called gluten. Make a piece of dough the size of a marble, and knead it in water in an old handkerchief. Starch comes through the meshes of the cloth and turns the water milky. When no further milkiness is caused in clear water, open the handkerchief and observe the grey sticky gluten. Test portions of it for protein by the xanthoproteic and Millon's tests. Gluten is plainly insoluble in water ; keep a little in salt solution for a day to learn if it is soluble in salt solution.

Reserve food materials in plants.—The presence of abundant food in many seeds accounts for their great importance in the diet of mankind, but the fact should not be lost sight of that the food was put aside for the use of the young plant (embryo) of

* Roughly, 2 ounces to the pint.

the seed during its early stages of growth. Fortunately, the food required by young plants also satisfies in many cases the needs of human beings as well as of many animals.

It will be seen in Chapter XII. that food reserves are often laid down not only in seeds, but also in various other parts, to be used afterwards by the plant at times when an extra quantity of food is required.

The principal kinds of reserve food materials occurring in plants are proteins, starch and various related substances, and oil. They do not occur in continuous masses, but take the

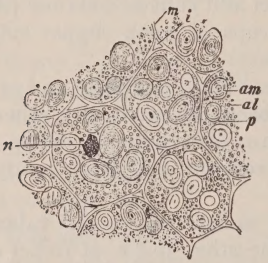


FIG. 12.—Part of section through one of the cotyledons of the Pea, showing three complete cells and parts of eight other cells, with reserve materials. *am.*, starch grains; *al.*, grains of protein; *p.*, protoplasm; *n.*, nucleus. (× 96.) (After Strasburger).

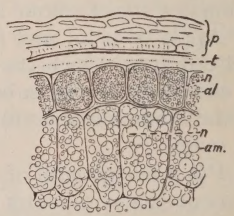


FIG. 13.—Part of a section through a grain of Wheat. *p.*, pericarp; *t.*, seed-coat; *am.*, starch grains; *al.*, grains of protein; *n.*, nucleus of cell. (× 120.) (After Strasburger.)

form of minute grains, or drops, etc., enclosed in cells (p. 91), which are too small to be seen satisfactorily without a microscope (p. 14). The food substances may be identified in bulk by the tests described on pp. 15 to 17.

Proteins.—Proteins form a group of substances of extreme importance, since they are an essential part of all living matter. This accounts for their presence, to some extent, in all seeds. Green plants are able to manufacture proteins from substances obtained from the air and the soil, but all animals require to be supplied with proteins ready-made, and die if these foods are withheld. Protein molecules are large and complicated; they consist of the elements carbon, hydrogen, oxygen and nitrogen, with a small proportion of sulphur, and in some cases a little phosphorus.

Although proteins resemble each other closely in chemical

composition, they show much variation in properties. Thus (Expts. *e*, *f*, p. 17) one of the proteins in pea cotyledons is soluble in water; another—present to a much greater extent—is insoluble in water but soluble in a solution of salt; while the principal protein (gluten) in the endosperm of the wheat seed is insoluble in both water and salt solution. For the most part, the proteins in seeds are insoluble in water but soluble in a solution of salt.

Carbohydrates.—Starch, cellulose and sugars belong to a group of compounds called carbohydrates. All carbohydrates consist of the elements carbon, hydrogen and oxygen only—the oxygen and hydrogen being in the same proportions as in water.

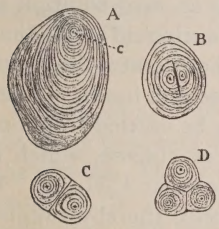


Fig. 14.—Grains of potato starch. (× 270.) (After Strasburger.)

Fig. 15.—Two starch grains of Haricot bean. (× 270.) (After Strasburger.)

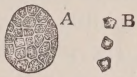


Fig. 16.—Oat starch. *A*, group of grains; *B*, three separate grains. (× 270.) (After Strasburger.)

Starch occurs in grains built up of concentric layers or shells. The grains vary greatly in size and shape according to the kind of plant in which they are formed; so that grains from potato, bean, maize, wheat, and oat, for example, can be readily distinguished from each other by means of the microscope. Starch turns blue at once on the addition of a solution of iodine, and is thus identified very readily. Its composition is $(C_6H_{10}O_5)_n$, where n represents an unknown quantity, probably about 100.

Cellulose (familiar in the form of "cotton-wool," and composing the finest quality of filter paper) is closely allied to starch. It consists of the same proportions of carbon, hydrogen and oxygen, but the molecule is greater, and may be written $(C_6H_{10}O_5)_m$. Iodine solution alone stains cellulose yellow, but iodine and sulphuric acid together turn it blue. The greater part of a date-"stone" (really a seed) or an ash seed is mainly

composed of cellulose; this constitutes the embryo's food during germination.

Inulin is a carbohydrate which replaces starch in certain circumstances. Unlike starch and cellulose, which it closely resembles in composition, it occurs dissolved in the water or "sap" of cells, so that it is not visible under the microscope until the water has been removed by washing the specimen with alcohol or glycerine.

Other carbohydrates are various **gums**, which absorb water readily and become slimy (*e.g.* the endosperm of the plant morning glory, p. 11). **Wood** is formed in plants by the alteration of cellulose. It can be distinguished from hard cellulose by the reddish violet colour given to it by treatment with an acid solution of phloroglucin. It is not coloured blue by sulphuric acid and iodine.

Sugars.—The various sugars are also carbohydrates, but with much smaller molecules than starch, cellulose and inulin. They are all soluble in water, and in solution can be carried from one part of the plant to another. **Grape sugar** or glucose, which is found in many ripe fruits, has the composition $C_6H_{12}O_6$. It readily unites with oxygen in living plant cells, thereby supplying energy for work and forming carbon dioxide and water:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + 6\underset{\text{oxygen}}{O_2} \rightarrow 6\underset{\text{carbon dioxide}}{CO_2} + 6\underset{\text{water}}{H_2O}.$$

The ready oxidation of grape sugar is illustrated by the formation of a brick-red precipitate of cupr*ous* oxide when it is heated (Expt. 2, *a*, p. 15) with Fehling's solution (an alkaline solution of a cupr*ic* salt). On this account grape sugar is called a *reducing sugar*. **Malt sugar** or maltose ($C_{12}H_{22}O_{11}$), formed during the germination of starchy seeds (p. 25), reduces Fehling's solution similarly, though less readily. **Cane sugar** or sucrose ($C_{12}H_{22}O_{11}$), abundant in sugar cane, beetroot, etc., does not yield a precipitate with Fehling's solution, but on boiling with a little acid (Expt. 2, *b*, p. 15) its molecule unites with a molecule of water and then splits into two molecules of reducing sugars, one being glucose and the other lævulose, which has a similar formula but different properties:

$$\underset{\text{sucrose}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O} \rightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{lævulose}}{C_6H_{12}O_6}.$$

The various **carbohydrates change readily from one to another** in the plant as occasion may require, by the addition or abstraction of water and the union or splitting of the molecules. We have just had an example of this in the conversion of cane sugar (sucrose) into glucose and lævulose. Still more striking are the change of a soluble carbohydrate like glucose into an insoluble form (starch) for storage (pp. 73 and 208) :

$$\underset{\text{glucose}}{n C_6H_{12}O_6} \rightarrow \underset{\text{starch}}{(C_6H_{10}O_5)_n} + \underset{\text{water}}{n H_2O},$$

and the reverse change of stored starch into soluble sugar for distribution : $(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6$.

Such conversions are of very great importance in the life of the plant. They depend on the presence of substances called **enzymes**, which are produced when and where the changes are needed. The action of the enzyme called *diastase* in promoting the conversion of starch into sugar is seen in Expt. 8, *b*, p. 25.

Oils.—Oils are also compounds of carbon, hydrogen and oxygen, but these elements are present in other proportions than in carbohydrates. Oils are soluble in ether, benzene and chloroform; castor oil is also soluble in alcohol. They are blackened by osmic acid, and turned red by the aniline dye Sudan III., and may be thus recognised.

Many plants store oil instead of starch as a food material, and very oily seeds (*e.g.* sunflower) are usually destitute of starch.

EXERCISES I.

1. Given an account of the structure and arrangement of the parts of *L*, illustrating your answer by an enlarged drawing of each part. [*L* = soaked castor-oil seed.] (C.J.)

2. Open the nut provided and dissect the contained seed. Make drawings to show the relative positions of its parts, and label the plumule, radicle and cotyledons.

3. Make large labelled drawings to show the essential differences between the structure of a pea and that of a maize grain.

4. Show clearly by drawings the *position* of the food stored in seeds of bean, oak, castor oil and wheat.

5. How would you determine the presence of glucose in a plant organ or germinating seed? Give an account of the test you would apply, and explain as fully as you can what happens. (Prel. Cert.)

6. What are the common reserve food materials stored in seeds and fruits ? Describe how any one of them is made available for assimilation by the plant. (Cert.)

7. What is the nature of the foodstuffs stored in a wheat grain ? By what tests can they be recognised ?
(L.M. part question.)

8. Write an account of the various food stuffs which are found stored in seeds. Describe simple experiments which would enable you to decide whether the seeds of a certain plant contained (*a*) nitrogenous matter, (*b*) starch. (O.S., General Science I.)

9. Give an account of the food materials stored in the seed of *either* Wheat *or* Bean. What happens to the stored food when germination occurs ? (J.M.B. Hr. Sch. Cert.)

10. By what simple tests can you show the presence of (*a*) starch, (*b*) cellulose, (*c*) grape sugar, (*d*) oil, (*e*) protein ? Mention seeds in which these food materials may be respectively recognised in abundance.

CHAPTER II.

THE GERMINATION OF SEEDS.

4. CONDITIONS NECESSARY FOR GERMINATION.

PRACTICAL.

1. Absorption of water by the seed.—Seal up the micropyles (p. 9) of a number of dry seeds of pea, beans, and melon by a drop of rubber solution. Also cover with rubber solution the arils of several dry castor-oil seeds and the pointed ends of several dry grains of maize, and sunflower fruits. When the solution has dried put the specimens with several untreated seeds into water and compare the readiness with which they absorb water. Do the various seeds chiefly absorb moisture through the micropyle or through the seed coat ?

2. Is light necessary ?—Line several tumblers or beakers with blotting paper, and fill the vessels with chopped sphagnum moss, cocoanut fibre, or sawdust. Soak the moss of one tumbler with water, and when the blotting paper has also become wetted, place seeds of radish, mustard, onion and grains of wheat and buckwheat (previously soaked in water for two or three hours) between the blotting paper and the glass. Put this tumbler in a dark cupboard or box, and examine after three or four days. Compare it with a similar arrangement exposed to light.

3. Is moisture necessary ?—Place similar seeds between the glass and dry blotting paper containing dry sphagnum. Do the seeds germinate ?

4. The effect of temperature.—If possible keep seeds (some previously soaked and others kept dry) in small bottles surrounded by a freezing mixture ; heat others (soaked and dry) for half an hour to different temperatures (up to 100° C.) in an air oven (Fig. 73). Afterwards test their germinating powers. Does

a freezing temperature injure the seeds permanently or merely delay their germination ? Are dry or soaked seeds more readily injured by (*a*) low, (*b*) high temperatures ? Sow broad beans and French beans together (*a*) in cold weather, (*b*) in mild weather. Which germinate first ?

5. Is oxygen necessary ?—Put a wad of wet cotton wool into one end of a U-tube and slide a few grains of wheat round the bend so that they are supported by the wet cotton wool when the tube is inverted. Close this end with a tightly fitting rubber stopper and place the other end in a solution of pyrogallate of potash * (which quickly absorbs oxygen from air to which it is exposed) as in Fig. 17. At once cover the solution of pyrogallate of potash with a layer of paraffin oil, to keep it from contact with the atmosphere. The seeds are thus exposed to air which within an hour will be deprived of all its oxygen, but of no other constituent. Notice the extent to which the liquid rises in the tube. Explain. Do the seeds germinate ?

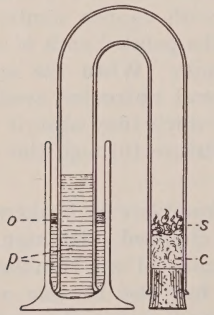


Fig. 17.—Experiment to show that seeds do not germinate without oxygen. *s*, seeds ; *c*, wet cotton wool ; *o*, layer of oil ; *p*, solution of pyrogallate of potash.

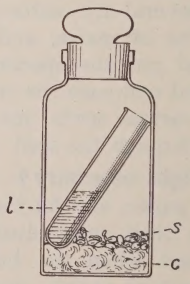


Fig. 18.—Experiment to show the changes which germinating seeds cause in the surrounding air. *c*, wet cotton wool ; *s*, seeds ; *l*, lime water.

6. Do germinating seeds give off carbon dioxide ?—Obtain two similar wide-mouthed well-stoppered 4 oz. bottles (Fig. 18). Put a layer of wet cotton wool in the bottom of each, and, on this, in one bottle (*A*) about 50 wheat or barley grains previously soaked in water for two hours ; in the other bottle (*B*) put a similar number of grains killed by boiling. In each bottle place a small, wide

* Made by dissolving 1 gram of pyrogallic acid (" pyro " as used in photography) in 15 c.c. of water, and adding to this *immediately* before use a solution of 5 grams of caustic potash in 15 c.c. of water.

test-tube containing a few c.c. of clear lime water, arranging the tube so that the lime water will not spill, and can be seen through the glass of the bottle. Close the bottles, smearing the stoppers with vaseline to keep them air-tight. Place the bottles side by side in a fairly warm place. What is the appearance of the lime water in *A* and *B* respectively when the seedlings in *A* have developed roots about an inch long ? Explain.

7. Do germinating seeds use up oxygen ?—Open the bottles in turn, plunging a lighted taper into each the moment the stopper is removed. Why is the taper extinguished in *A* and not in *B* ? Why is it necessary to observe the condition of the lime-water before testing with the taper ?

8. Formation of sugar in starchy seeds.—(*a*) Chew germinating barley grains, or the cotyledons of a germinating pea, and notice the sweet taste. Compare the taste of similar ripe seeds in which germination has not begun.

(*b*) Germinate about fifty barley grains until the roots are about an inch long. Grind them in a mortar with a little water, and pour off the liquid "malt extract" thus obtained. Add it to half the cooled "starch paste" obtained by boiling in a cupful of water as much starch as will lie on a threepenny piece, and keep the mixture lukewarm. Test portions of it at intervals with iodine solution, and notice that no starch can be detected after a short time. Test for sugar with Fehling's solution (p. 491). The starch has changed into a kind of sugar called maltose or malt sugar (p. 20).

Dry seeds.—Before a plant sheds its seeds, a very large proportion of the water, which was present in them during the ripening period, is withdrawn, so that they become dry and correspondingly hard. Their hardness protects the seeds from being devoured so readily by many animals, while the practical absence of water saves them from injury by extremes of temperature which would be fatal to almost all other living things. Naturally dry seeds can withstand prolonged exposure to hard frost, and some even survive heating to the temperature of boiling water for a short time, without losing their power of subsequent growth ; whereas seeds previously soaked in water are killed by such extremes of temperature.

The stage of life through which a plant passes in the ripe

seed is a **resting period**, which varies considerably in length in different species. Some seeds (*e.g.* wheat, shepherd's purse, chickweed, groundsel, etc.) are capable of germination immediately they are shed by the parent plant. Sycamore seeds cannot be induced to germinate until the spring following their formation, and ash seeds are said to require two years' rest.

On the other hand, seeds differ widely in the length of time for which they can retain their vitality if the conditions necessary for germination are postponed. Some seeds are said to have survived a resting period of 100 years.

The conditions of germination.—The embryo contained in the seed is stimulated to growth, or germination, by the absorption

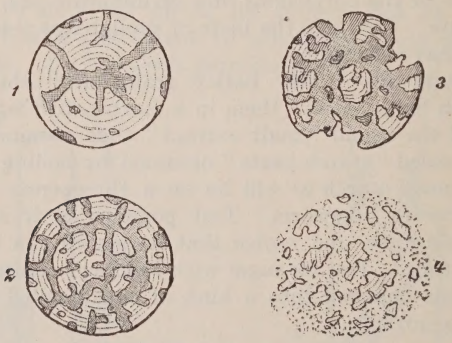


FIG. 19.—Different stages of the corrosion by diastase shown by the starch grains of germinating Barley. (After Noll.)

of **water**, if at the same time a supply of **oxygen** and a **suitable temperature** are available. The temperature necessary varies. Thus, French beans need more warmth than broad beans, and therefore germinate later in the spring. Light is not necessary for the earliest stages of growth, as is evident from the fact that most seeds usually germinate under the surface of the soil.

The water is probably absorbed in some cases through the seed coat; in most cases it apparently enters entirely by the micropyle (p. 9), and thus reaches the radicle first. It soon makes its way to other parts of the seeds by "capillary action" (in the manner in which water passes to all parts of a sheet of blotting paper supplied with water at one place only). The living embryo,

thus supplied plentifully with water at the proper temperature, begins to manufacture small quantities of substances called **enzymes** (p. 21), which change the food materials into forms soluble in water and capable of passing in solution to all parts of the young plant. In starchy seeds, for example, there is produced the enzyme called diastase—specially abundant in germinating barley—which changes insoluble starch into a sugar (maltose) (Expt. 8, *b*, p. 25). In a similar manner other stored foods, such as proteins, oils, and cellulose, are acted upon by their appropriate enzymes and changed into soluble food materials which pass in solution to the waiting growing-points, where they are used.

Respiration.—The dissolved food which makes its way to the growing-points of the embryo plant is used in two ways. Much of it furnishes the *material* of which the new tissues are built up. Another part of the food is used, so to speak, as *fuel*, and is "burnt" to supply energy. The plant's energy is chiefly derived from the breaking down of a complex compound, sugar, when the latter unites with oxygen to form the much simpler compounds carbon dioxide and water; and it is in this way that the oxygen (which Expt. 5, p. 24, shows to be necessary for germination) is used:

$$\underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} = \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O}.$$

In this process, which is called **respiration**, the locked-up or "potential" energy of the sugar is released; part is used in doing the work, mechanical and other, upon which the young plant has now actively entered (pp. 127 and 166); part takes the form of heat, which at times of special activity causes a distinct rise of temperature. Thus, a thermometer with its bulb buried in germinating seeds or opening flower-buds in a vacuum-flask may register a temperature several degrees higher than another thermometer placed under similar conditions among dead or resting seeds or buds.

The respiration of a plant or animal shows itself most obviously by absorption of free oxygen from the outside air or water, and by the liberation of carbon dioxide (Expts. 6, p. 24,

and 7, p. 25). The respiring part clearly undergoes a loss of material. Respiration takes place much more slowly in plants than in animals, as one would expect from the smaller amount of mechanical work which plants do. In green plants respiration is often *masked* by photosynthesis (Chap. IV.), which has the opposite effect.

5. HYPOGEAL AND EPIGEAL GERMINATION.

PRACTICAL.

The stages of germination.—Plant in soil the seeds mentioned in Chapter I., each at a depth equal to its diameter, and make drawings to show especially the following features :

1. The first sign of germination.—Which part of the embryo is the first to leave the seed coat ? In which direction does it grow ? Try to persuade it to grow in the opposite direction by turning the seed over. In what way is it an advantage to the plant that this part should leave the seed coat first ? Which part of a bean embryo is nearest the chief point of entry of moisture into the seed ? In what respect is this fact useful to the embryo ?

2. The root system.—In which of your seedlings does the first root remain the main root ? Are these plants dicotyledons or monocotyledons ? In what order do the branches of the main root appear ? Are they outgrowths of the surface of the main root or do they burst through the surface from the interior ? What is their direction of growth ? In other seedlings, notice the position of origin of later roots which are not branches of the first root. What is the direction of their growth ?

After the root, which part of the embryo next begins to grow vigorously ? Make a drawing of a good specimen of each kind to show the condition of the root system at this stage. Is the root firmly anchored in the ground at this stage ? If so, how ?

3. The hypocotyl.—In which seedlings is the hypocotyl (the upper part of the radicle, next below the cotyledons) the next part to grow vigorously ? What effect has its growth upon the position of the cotyledons and plumule ? Would this effect be the same if the root were not already fixed firmly in the soil ? In vegetable marrow or melon seedlings look for a peg-like outgrowth at the bottom of the hypocotyl. Make a drawing, and write notes on the evident use of the outgrowth. Describe

any differences in colour, thickness, surface, etc., which enable you to distinguish between the root and hypocotyl of the various seedlings. Put several seedlings into a four per cent. solution of potassium permanganate for five minutes and notice to what extent root and hypocotyl respectively are stained brown.

In this group of seedlings, which part of the embryo is the first to appear above ground? Does this behaviour protect any specially tender region from injury by friction with the soil? If so, explain how. How does the growth of the hypocotyl affect the position of the cotyledons? Describe the behaviour of the hypocotyl and the cotyledons after the cotyledons have come through the soil. At what stage, and how, is the plumule exposed to the light and air? What is now the appearance of the cotyledons? What is the condition of the plumule when the cotyledons begin to wither?

4. The plumule.—In which seedlings does the hypocotyl remain short, so that the cotyledons stay below the surface of the soil? How does the plumule behave in these cases? Examine germinating seeds of the broad bean, pea and oak for signs of *elongation of the stalks of the cotyledons*. Is the plumule thereby liberated from the seed coat or pericarp? Which part of the seedling broad bean or oak first comes above the surface? How is the plumule-bud protected from the friction of the soil, (*a*) in the broad bean, runner bean, pea and oak, (*b*) in wheat and maize.

Make drawings of the stages of germination of *onion*. The long green rod, on the end of which the seed coat is usually raised above the ground, is the single cotyledon. Notice how the plumule is liberated by bursting through the base of the cotyledon. Compare, if possible, the stages with those of the slower germination of the seed (stone) of the *date*.

5. The cotyledons.—Remove the cotyledons from seedlings of pea, broad bean, runner bean, or oak, and compare the later growth with that of uninjured seedlings of similar kind. Notice the gradual shrinkage of the cotyledons of such uninjured seedlings as the leaves of the plumule unfold. What is evidently the use of the cotyledons in normal seedlings of these plants?

Classify the seedlings studied, in groups according as the cotyledons (*a*) seem to act merely as storehouses of food; (*b*) come above the soil and obviously behave as leaves; (*c*) combine (*a*) and (*b*); (*d*) seem to absorb endosperm; (*e*) combine (*d*) and (*b*).

Remove the plumule-bud from several seedlings of various kinds, and notice that this causes the plumule to branch just above the point of attachment of each cotyledon-stalk. Examine various older plants to find out at what places the stem branches, and describe any evidence you obtain that cotyledons are more or less modified leaves.

6. Comparison and contrast.—Draw diagrams of the seedlings of broad beans (or of runner bean, pea or oak), French bean (or of lupin, sunflower or sycamore), castor oil, maize (or wheat) and onion; in each case indicate the level of the soil; colour the plumule green, the cotyledon(s) yellow, the hypocotyl pink, the root brown and the endosperm (if present) blue.

The germination period.—The period of life during which the embryo of a ripe seed develops into a plant capable of making its own food is called the period of germination, and the plant itself during this time is known as a **seedling**. Because, as we shall see later (Chap. IV.), food is made only by the green parts of plants, of which the leaves are much the most effective, the germination period may be considered to end with the liberation of the plumule and the unfolding of the bud at its tip to spread out the contained foliage leaves to the light and air. It is interesting to notice how in each case the various events leading up to this important stage follow each other in exactly the order which best ensures the young plant's efficient development.

The root of the seedling.—The first and most pressing need of the seedling is machinery for securing a regular supply of water, and it is significant that the early stages of germination are always occupied in the establishment of a root system, capable of ensuring such a supply. Germination begins by the absorption of water into the seed, and in the great majority of cases the water enters through the micropyle or by some other absorbing apparatus (*e.g.* the aril of the castor-oil seed) which is close to the radicle. It is not surprising, therefore, that the root is the first part of the embryo to begin active growth. It bursts through the seed coat and, pushing against the weight of soil

above it, makes its way directly *downwards* into the soil, bending, however, towards any part moister than the rest, or turning aside to circumvent a pebble in its path. In later chapters we shall learn something of the means by which the root is impelled to behave in a manner so helpful to the plant's general welfare, and shall study the way in which it grows in length and absorbs water.

The root is soon firmly fixed in position. This result is brought about, first, by means of a zone of very fine hairs (**root hairs**), which grow on its surface a short distance behind the tip (Fig. 20) and become closely attached to the neighbouring particles of soil; and, secondly, either (*a*) by side branches growing from the older parts of the main root (Figs. 24, 86, etc.), or (*b*) (in all monocotyledons (Figs. 27, 29) and many dicotyledons) by extra or adventitious roots springing from the base of the stem—each branch or extra root having its own patch of root hairs near its tip. The resulting **firm anchorage of the root system** is important, for it ensures that any increase in length of the rest of the axis of the embryo will take place in an upward direction.

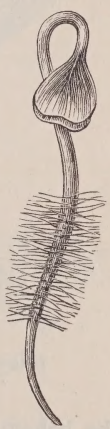


Fig. 20.—Early stage of Radish seedling, showing root-hairs. (After Duggar.)

The stem of the seedling.—It is next the turn of the young stem to grow in length. The stem, however, consists of two distinct regions, one above and the other below the cotyledons (p. 32). The former portion of the young stem is therefore called the *epicotyl*;* the latter is the *hypocotyl*.† The **epicotyl** is the part of the plumule between the cotyledons and the terminal bud. The **hypocotyl** is the upper part of what we have called the radicle; the lower part of the radicle becomes the first root.

The two portions of the developing radicle are easily distinguished from each other; the root is thinner than the hypocotyl and generally begins to branch at its upper end.

* Greek: *epi*, above. † Greek: *hypo*, below.

Moreover, when a seedling is placed in a four per cent. solution of potassium permanganate, the root is quickly stained brown; the stem region (including the hypocotyl) remains unstained for a much longer time.

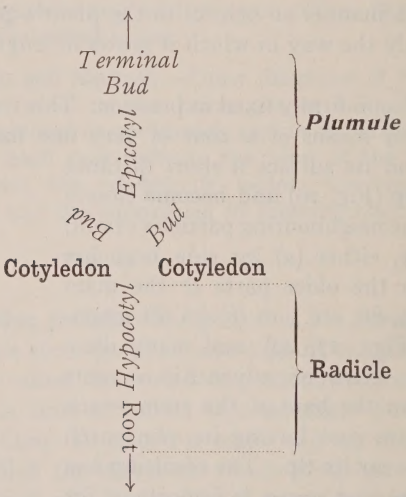


Diagram to show the regions of the embryo of a dicotyledon. The names of parts of the stem are printed in italics.

The behaviour of the cotyledons.—The *manner* in which the stem grows longer, and the means by which it finds its way upwards as persistently as the main root finds its way downwards, will be considered later. At present we must think rather of the *effect* which the growth of the young stem has upon the position of the cotyledons. Evidently this effect will be different according as (*a*) the hypocotyl or (*b*) the epicotyl is the part of the stem to elongate first, since by this time the root is fixed too firmly to be pushed downwards by their growth.

Any vertical elongation of the hypocotyl will clearly tend to lift the cotyledons and plumule upwards (Figs. 21 to 23). On the other hand, vertical growth in length of the epicotyl alone at this stage will leave the cotyledons undisturbed, but will tend to raise the terminal bud of the plumule above the soil

(Fig. 24). There are thus two chief types of germination: one (called **epigeal***) in which the cotyledons are lifted above the surface; and another (called **hypogeal***) in which the cotyledons remain buried in the soil, and the plumule alone (previously

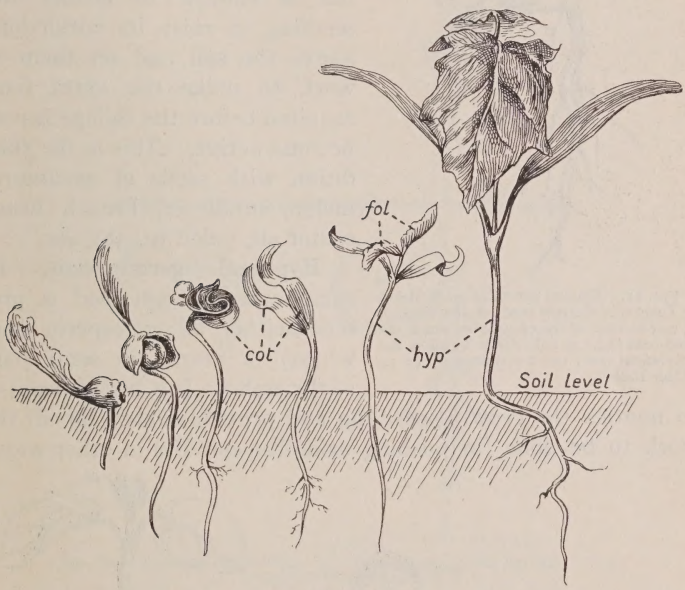


Fig. 21.—Epigeal germination of a Sycamore seed (exalbuminous). *cot.*, cotyledons; *fol.*, first pair of foliage leaves; *hyp.*, hypocotyl. (Modified from Miller: *Cornell University Nature Study Leaflets.*)

liberated from the seed coat by elongation of the cotyledon stalks in such cases as oak, broad bean and pea) comes above the ground.

The great importance of the cotyledons is shown by the fact that their removal at an early stage interferes seriously with the development of any seedling, and may even cause its death from starvation.

Epigeal germination.—The different behaviour of the cotyledons, seen in Figs. 21 to 29, is apparently associated with the proportion of food stored in the seed. In most seeds, the

* Greek: *ge*, the earth.

amount of food present at the beginning of germination is not sufficient to supply the needs of the plant until the foliage leaves of the plumule-bud are ready to take up their duties, but is enough to enable the seedling to raise its cotyledons above the soil and set them to work to make the extra food required before the foliage leaves become active. This is the condition with seeds of sycamore, melon, sunflower, French bean, castor oil, onion (p. 38), etc.

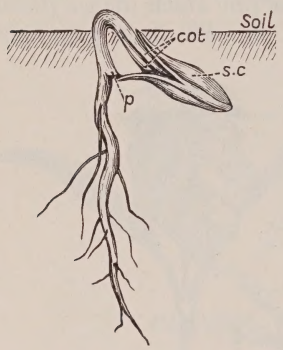


FIG. 22.—Epigeal germination of Melon or Vegetable Marrow seed (exalbuminous). *p*, peg at base of hypocotyl, by which the seed-coat (*s.c.*) is held down to allow the cotyledons (*cot.*) to be withdrawn. (× 1.) (After Bailey.)

Hypogeal germination. — In some cases enough food is present—either as endosperm (*e.g.* wheat) or stored in some part of the embryo (*e.g.* broad bean)—to nourish the growing seedling and provide energy for all the work to be done (in pushing aside the soil and in other ways)

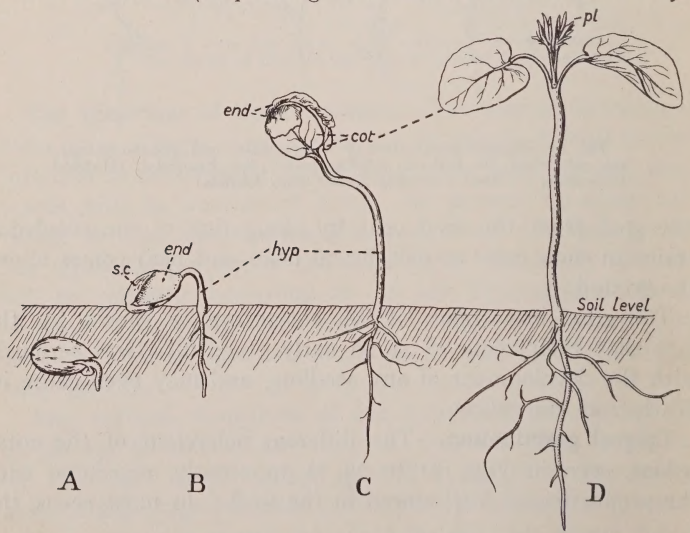


FIG. 23.—Epigeal germination of Castor Oil seed (albuminous). *s.c.*, seed-coat; *end.*, endosperm; *cot.*, cotyledons; *hyp.*, hypocotyl; *pl.*, plumule. (× ⅔.)

until the young plant has unfolded the leaves of its plumule to the light and air and is able to make its own food. In such cases the cotyledons remain in the soil, either digesting and absorbing the endosperm and passing it on, as needed, to the stem

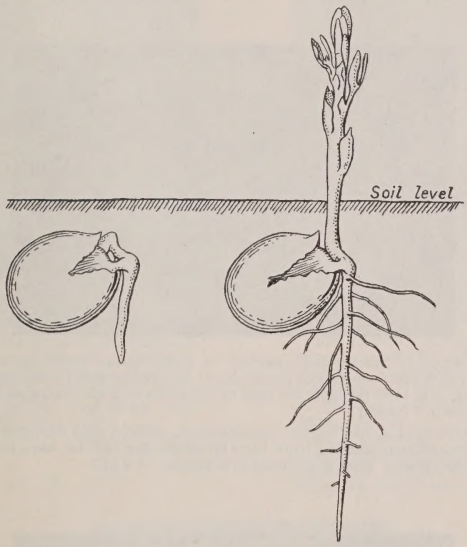


Fig. 24.—Hypogeal germination of Broad Bean (exalbuminous). (× ½.) (After Thompson.)

and roots of the young plant (*e.g.* wheat), or gradually shrivelling as the food they themselves contain is drained off and used by the stem and roots (*e.g.* broad bean, pea, oak).

The nature of cotyledons.—In certain cases the cotyledons evidently behave as leaves. That they really are true leaves, specially modified for service during the seedling stage, is indicated by their leaf-like colour, general shape, veins, etc., in these cases; even when they are not leaf-like in appearance, their nature is shown conclusively by the fact that (like ordinary foliage leaves) they bear buds in their axils *—buds which can and do grow out to form branches if any accident befall the plumule.

* The axil of a leaf (p. 46) is the upper angle between the leaf and the stem on which it grows (Latin, *axilla*, the armpit).

Figs. 25 to 29 are from photographs of models illustrating stages in the germination of Wheat (typical of grasses), exhibited in the British Museum (Natural History). (By permission of the Trustees of the British Museum.)

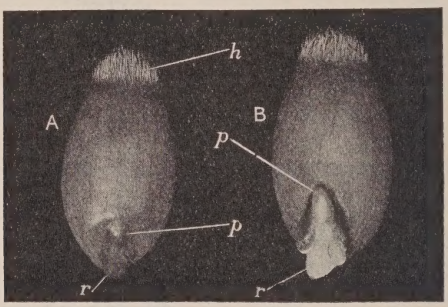


FIG. 25.— *A*. Wheat grain swollen in water before germination. The embryo with the young shoot (plumule, *p*) and young root (radicle or primary root, *r*) is seen through the coat of the grain: *h*, stiff hairs on the top of the grain. (× 3½.)

B. Germination has begun; the plumule, radicle, and first pair of adventitious roots (springing from the axis above the radicle) have burst the coat of the grain; each is enclosed in a sheath. (× 3½.)

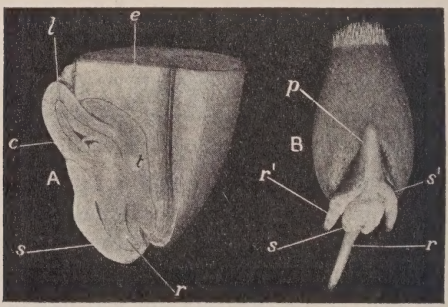


FIG. 26.— *A*. Longitudinal section through the lower part of the grain at the stage shown in Fig. 25, *B*. The section shows the primary root, *r*, within its sheath, *s*, and the plumule with its sheath, *c*, the first foliage leaf, *l*, and the enclosed bud. A shield-like outgrowth of the axis of the embryo, the cotyledon, *t*, separates the plumule and radicle from the store of nourishment, the endosperm, *e*, of which the rest of the seed consists. The cotyledon absorbs the food stored in the endosperm and conveys it to the growing seedling. (× 5.)

B. The plumule has elongated, and the primary (*r*) and two adventitious roots (*r'*) have broken through their respective sheaths, *s*, *s'*. (× 2½.)

FIG. 27.—The plumule has elongated further; a second pair of adventitious roots has appeared above the first, and root-hairs have developed on the other roots, which have grown considerably in length. (× 2.)

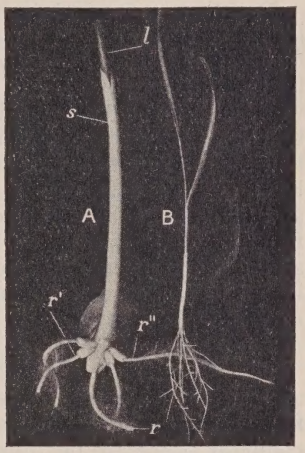


FIG. 28.—*A*. The first green leaf, *l*, has now burst through the plumule-sheath, *s*. The second pair of adventitious roots (*r''*) is now well developed. All the roots but one have been cut off short. (× 1½).

B. A later stage. A seedling showing the first two green leaves emerging from the plumule-sheath, and the complete root-system. (× ⅓.)

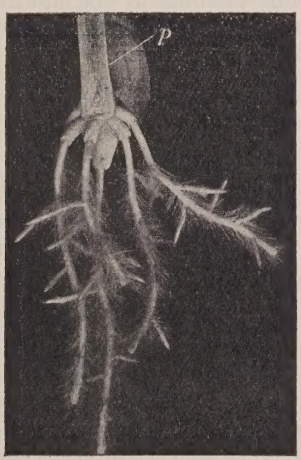


FIG. 29.—The lower part of a stage later than Fig. 28, *A*, showing the plumule in section; the bud enveloped by the bases of the first two green leaves can be seen. A fifth adventitious root has appeared on the left-hand side. The roots, which have been cut off short, bear numerous lateral branches (secondary roots). (× 2.)

Physiology and morphology.—Cotyledons serve excellently to illustrate several terms which it will be convenient to use in future. The study of the work or (so to speak) the duties of any part of a plant or animal is called **physiology**; and the special work of the part in question is called its **function.** Thus the function of the broad bean's cotyledons is to serve as a store-house of food; the functions of the cotyledons of the French bean, sycamore, sunflower and melon are two: (*a*) to store food and (*b*), when this food is consumed, to make more food; the function of the wheat cotyledon (scutellum) is to digest, absorb and distribute the endosperm; the castor-oil and onion cotyledons have not only a similar function to that of the wheat cotyledon, but, in addition, they perform the function of making new food.

The study of the structure or "build" of plants, or animals, and their parts is called **morphology.** This side of botany shows, for example, that roots have certain essential characters in common which are not found in stems, and *vice versa*; so that it is possible to distinguish roots from stems and stems from roots even when these plant "members" are of very unusual appearance and manner of growth.* Similarly, leaves have certain peculiarities, in structure and in their mode of origin from stems, which can be recognised even in cotyledons and various other structures which at first sight do not resemble leaves. We are thus justified in the morphological statement that **cotyledons are leaves,** more or less modified in accordance with the special functions they perform.

The protection of the terminal bud.—In our **dicotyledonous** types, the part of the seedling which first comes above the surface of the soil is the top of an **arch** which has formed by bending of the developing epicotyl or hypocotyl (Figs. 20, 22 and 153). In hypogeal types the arch ensures that the terminal bud of the plumule is *pulled* up—base first—through the soil, instead of being pushed straight up with the tip first, and is thus saved from much injury by friction with the soil. In epigeal types, the cotyledons are similarly safeguarded, and the terminal bud has the additional protection of being enclosed between the cotyledons until it and they are free from the soil.

Among **monocotyledons,** the onion seedling is epigeal; its plumule is enclosed in the tubular cotyledon, which grows

* Chap. XII.

rapidly after the root has become established, and forces its way through the soil by a crook like that on the stem of a dicotyledon seedling. In the wheat, the tip of the plumule is enclosed in a hard and *sharply-pointed sheath* which pierces the soil as the plumule grows straight up.

Exposure to the light soon causes the crook in the epicotyl or hypocotyl to straighten out; also it stimulates the tip of the plumule of the onion and wheat to burst through its sheath (Fig. 28, *A*).

In all our types, we may consider that, when the terminal bud of the plumule has unfolded, the critical period which we call germination is at an end. The temporary means of nutrition afforded by the original food stored in the seed, and supplemented in many cases by new food made by the cotyledons, is by this time almost exhausted; but it is no longer required, since in the foliage leaves the plant has now mobilised the means of making new food according to its needs.

EXERCISES II.

1. How would you show what conditions are necessary for the germination of a seed ?

2. Describe in detail an experiment to prove that germinating seeds respire.

3. Given some germinating peas, how would you demonstrate the process of respiration ? How would you show that heat is given out during this process ? (J.M.B. Sch. Cert.)

4. A sensitive thermometer placed among a pile of germinating barley grains in a box registers a higher temperature than does a similar thermometer placed among some dry barley grains. Explain as fully as you can the reason for this, and the botanical importance of the observation. (C.S.)

5. Give as detailed a chronological account as you can of what happens from the time when a dry seed is sown until the time when the first foliage leaves of the plant appear.

6. Describe the structure of a seed of *either* wheat *or* maize. How would you demonstrate experimentally the conditions which are necessary for its germination ? (J.M.B. Matric.)

7. Why are French beans sown later in spring than broad beans ? Mention *three* essential conditions for germination of seeds, and say how you would demonstrate experimentally that these conditions are essential. (J.M.B. Jun. Cert.)

8. Give an account of the structure and germination of the bean seed (or any similar seed), and point out how the germination differs from that of the melon seed.
(J.M.B. Sch. Cert. and Matric.)

9. What do you know of the hypogeal and epigeal positions of cotyledons in germinating seeds? Give examples, and explain the part taken by the cotyledons in the nutrition of the young plant. (J.M.B. Hr. Sch. Cert.)

10 Write a description of the structure and mode of germination of the bean seed. Illustrate by careful drawings. Point out what happens to the cotyledons, and say how the shoot makes its way out of the ground. How can you tell that the cotyledons are modified leaves? What is their function in this plant? (J.B.M. Sch. Cert.)

11. State clearly the difference between an albuminous and an exalbuminous seed.
Describe the structure and the early stages of germination of *one* example of each class. (O.S.)

12. Describe, by means of labelled sketches, the various stages of germination (up to the appearance of the first foliage leaves) of an exalbuminous seed and of an albuminous seed, naming the seed in each case. (L.M.)

13. Describe the structure of two seeds having endosperm and of two which have none. Compare the behaviour during germination of the seeds you select. (N.F.U.)

14. Give an account of the changes which take place during the germination *either* of the broad bean *or* of the melon. Describe the cotyledons, pointing out why they are regarded as leaf structures, and explain carefully the changes which take place in them as the seedling plant becomes established. (J.M.B. Matric.)

15. What is a cotyledon? Give brief descriptions of examples illustrating the different functions performed by cotyledons.
(J.M.B. Hr. Sch. Cert.)

16. What is the hypocotyl? Mention plants in which the hypocotyl elongates during seed-germination, and others in which it remains short. Account, as far as you can, for the difference.

17. Give a detailed account of the germination of (1) maize *or* wheat and (2) bean *or* pea, illustrating your account by careful drawings of different stages. Explain how the growing parts are supplied with food in each case. (J.M.B. Hr. Sch. Cert.)

18. Describe carefully the germination of a grain of wheat. What are the conditions which favour germination? Point out how the young plant is nourished, and indicate the nature of the food materials it utilises. (J.M.B. Matric.)

CHAPTER III.

THE LEAFY SHOOT OF THE FLOWERING PLANT.

6. THE POSITIONS OF LEAVES, BUDS AND BRANCHES.

PRACTICAL.

1. Some needs of plants.—(*a*) Examine the plants of hedges, woods and gardens, and make notes of any evidence you find that they need a good supply of light.

(*b*) Study the arrangement of the leaves of ivy, privet, daisy, plantain, etc., and of those on the twigs of various trees, and draw any specimens the leaves of which seem by their position to secure the most light possible.

(*c*) Pull a weed out of the soil and leave it lying exposed to light. Describe and explain the result.

(*d*) Compare the growth of seedlings in (i) soil and (ii) damp moss. Mention any evidence you find that plants or sawdust take up something besides water from the soil.

2. Leaves and branches of the stem.—Watch the further growth of various seedlings, and notice that all leaves on the main stem arise by unfolding of the *terminal bud*. Look for other buds in the axils of the leaves (p. 35). What becomes of the *axillary buds?* Do all the branches arise in the axils of leaves? How does a branch resemble the stem on which it grows? Does it end in a bud? *How could you distinguish between a stem and a branch growing on it, if the branch were the larger?* Examine a gorse twig, and distinguish between the needle-shaped leaves and the needle-shaped branches in their axils. Examine a leafy hawthorn twig; what evidence do you find that the thorns are short pointed branches?

3. A typical bud.—(*a*) Split a cabbage, a Brussels sprout, or a lettuce "heart" *down the middle*, and draw the section. Look

for buds in the axils of the leaves, and show them in the drawing.

(*b*) Cut *across* well developed end buds of various plants (*e.g.* laurel, rhododendron, elder, plum or blackthorn) with a sharp knife or razor, and examine and draw the sections. Watch the leaves unfold when similar buds expand.

4. Phyllotaxis.*—Examine leafy stems and branches, and make out the following particulars : Are the leaves *alternate* (one leaf only at each level), *opposite* (two leaves at each level), or *whorled* (more than two leaves at each level) ? If alternate, are the leaves attached to the stem in 2, 3, 5, or 8 rows (look at the stem "end on" to see this) ? In cases where the rows are more than two, join up the leaf bases by a cotton thread passing spirally from each leaf to the next. How many times does the thread pass round the stem before coming to a leaf just above the starting point ? Draw good "rosettes" of daisy, plantain, etc.

The general build of a flowering plant.—The seeds studied in the first chapter were found to be alike in certain important respects, although they were different in others. Each contains an embryo or young plant, which consists of a young stem, a young root, and either one or two leaves growing on the stem. This plant—so simple before germination—becomes more and more complex as it grows older, but to the end of its life the distinction between the root parts and the stem parts remains more or less clear. The stem, with the leaves and branches of various kinds (including flowers and fruits) which grow on it, are spoken of together as the shoot, so the whole plant is said to consist of **shoot** and **root.**

Usually, the whole of the shoot grows in the air, while the root part is buried in the soil. There are many exceptions to this condition, as we shall soon see, but the general rule gives a clue to the outstanding differences in the shares taken by shoot and root respectively in the activities of the whole plant. In the same way a general knowledge of the functions of the various parts of the plant helps to explain their shapes and relative positions.

* Greek, *phullon*, a leaf ; *taxis*, arrangement.

These functions are of two kinds :

(1) **Reproductive** activities are those which have to do with the making of new plants ; in flowering plants, reproduction is the work of the flowers.

(2) **Vegetative** activities are those concerned with nutrition and growth ; it is this side of a plant's life-work and the machinery for carrying it out which will first occupy our attention.

Plant nutrition and light.—It is a matter of common experience that plants growing in well-lighted situations—other conditions being equal—are in every way more vigorous and better nourished than those growing in shady places. When a hedge runs east and west, the plants on the sunny south side are noticeably more numerous and healthy than those on the shaded north side. Birch and oak woods, which do not cast deep shade, have relatively abundant undergrowth (Fig. 179) ; while beech trees form so close a canopy of foliage (Fig. 330) that the light beneath is very dim, and hardly any green vegetation grows under them. Plants growing on a window sill turn their leaves and bend their stems towards the light ; the weeds in a hedgerow seem obviously struggling to raise themselves above their neighbours. Everyday observation of plants will show numberless other examples of their dependence on light.

It is almost equally plain that the **leaves** are the parts of the plant which are most sensitive to light. Scarcely a British plant can be examined attentively without furnishing some evidence of this in the arrangement of its leaves in a manner which secures the greatest possible amount of light without interfering with their neighbour's supply (p. 49). Moreover, the fact that foliage leaves are almost universally *green* suggests that the exposure of essentially green parts to the light is a condition of the ordinary plant's welfare.

Plant nutrition and the soil.—Let us now turn our attention for a moment to the importance of the soil to plant life. We know that if we neglect to water a plant growing in a pot, the plant will die. It thus seems that healthy plants obtain *water* from the soil. That water is not all is shown by the fact that seedlings growing in damp moss or sawdust, or in clean damp sand, presently wither and die ; while those grown in soil flourish, and

with proper care come to maturity. Evidently soil contains something, besides water, which plants need.

Such well-known facts as those just mentioned are of fundamental importance in the study of plant nutrition, and our future work in this side of botany will consist largely in the following up of clues to be obtained from them.

The main functions of leaf, root and stem.—All the evidence available goes to show that a plant's food (upon which it depends for growth and all its various activities) is made only in its green parts, when these are exposed to light and supplied with certain raw materials (not in themselves food) which are obtained partly from the soil and partly from the air. It is clear that if (as the experiments described on pp. 61 and 62 prove) light is needed for this work, **food-making must of necessity be done above the soil.** Further, since some of the materials needed in the process are got from the soil, the above-ground parts of the plant which are engaged in food-making must be kept in connection with the parts in the soil.

It is important that these fundamental conditions should be understood, because they give a clue to the common general plan of architecture which, in spite of numberless minor variations, is to be found throughout nearly all the higher plants. They show at once (1) that it is an advantage for most of the green material (which makes the food) to be contained in thin flat plates (leaves), because in that way a given amount of green material receives the most light; (2) that leaves in general are best able to do their work when they are raised well above the ground (because they are less likely to be overshadowed); (3) that the chief uses of the stem are to expose the leaves to light and connect them with the roots; (4) that the common *upright* habit of growth of stems best ensures a good supply of light for the leaves; and (5) that roots which branch freely and spread about in the soil, as most roots do, can not only obtain greater supplies of the needed material from the soil, but are best able to support and anchor the stem with its weight of leaves and branches.

The growth of leaves on stems and not on roots, which thus seems so natural, has become so fixed a condition that the presence of leaves, however reduced or modified, on any part of

a plant may be considered by beginners to stamp that part as being of the nature of a stem, even though it may grow in the soil and in other respects have the appearance of a root (*v.* Chapters XI. and XII.).

The origin of leaves from the stem.—The actual growing tip of a stem or a branch of a stem is covered by a cluster of immature leaves. Such a stem tip, together with the cluster of leaves surrounding it, is called a **bud.** *It is characteristic of stems and their branches that, so long as they remain able to grow in length, they end in a bud.* When a bud (a cabbage, lettuce or Brussels sprout is convenient for study because of its large size) is split down the middle, the tender conical tip or "growing point" of the stem is seen to be surrounded by leaves of various stages of development. Those nearest the tip are so small as to be scarcely recognisable as leaves, but further back the leaves are larger and more completely developed. As the tip moves on, to increase the length of the stem, new leaf rudiments appear round it, whilst those previously existing increase in size as they are left behind. In this way it comes about that the leaves are attached to the stem in such an order that the youngest is always the one nearest the tip of the stem or branch on which it grows. In other words, the positions of leaves are in order of their age. This order is called **acropetal* succession.**

FIG. 30.—Common Cabbage at end of first year's growth. (After Nicholson.)

The young leaves in a resting winter bud are protected from the dangers of drying, mechanical injury, the attacks of insects and moulds, etc., by being surrounded by overlapping scales (Fig. 32) consisting of more or less modified outer leaves, which are tough, woody, hairy or soaked in resin in different cases (pp. 175 and 431). The young leaves gain additional protection

* *i.e.* tip-seeking.

by their own close packing in the bud. This is secured by various methods of folding (Figs. 37, 38 and 117).

The **axil** of the leaf (the upper angle between a leaf and the stem bearing it) is an important region, since, in flowering plants, a stem-branch arises almost invariably as a bud in the axil of a leaf (Figs. 97, 98 and 327). Such *axillary buds* are often recognisable (by dissection) even before the leaves themselves have unfolded (Figs. 31 and 109).

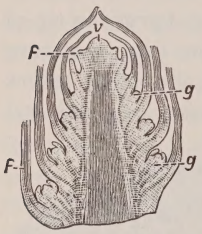


Fig. 31.—Longitudinal section of a terminal bud; *f.*, leaf-rudiments; *g.*, axillary buds; *v.*, "growing point." (× 20.) (After Strasburger.)

The level at which a leaf is attached to the stem is called a **node**, and the length of stem between two successive nodes is called an **internode**. In a bud the internodes are very short, and the leaves are consequently very close together. The "rosettes" of leaves found in such plants as daisy, dandelion, plantains (Fig. 193), primrose, etc., are formed by the suppression (failure to develop) of the internodes at the ground level. Leaves which grow on the part of a stem which is above the ground are described as *cauline*; foliage leaves growing on the underground part of a stem are called *radical* leaves, because they *appear* on casual examination to spring from the root.

Phyllotaxis.—Apart from order of age, leaves are spaced on a stem in a definite relation to each other, which is generally constant for the same kind of plant, and is called the phyllotaxis of the plant. Sometimes (*e.g.* heather (Fig. 172), mare's-tail and water milfoil), three or more leaves grow at the same node. Such a group is called a whorl of leaves, and the phyllotaxis of the plant is said to be **whorled.** In many plants (*e.g.* sycamore, horse chestnut, ash, privet, deadnettle, etc.) two leaves grow at the same level, on opposite sides of the stem, and the direction of each pair crosses that of the next pair (Fig. 33).

Fig. 32.—Beech twig in winter, with three resting buds. *k*, bud scales. (× 1.) (After Strasburger.)

Such a phyllotaxis is described as **opposite and decussate** (crossing).

In most cases, only one leaf grows at each node. This is called the **alternate** arrangement. In iris (Fig. 159), grasses, broad bean,

Photo. Henry Irving.

Fig. 33.—Leafy shoot of Sycamore and diagram of its phyllotaxis (opposite and decussate). Compare with Fig. 117.

and the longer twigs of elm (Fig. 34), beech, hazel, and a few other trees, the leaves are alternate and *two-ranked*, the leaf at one node being on the opposite side of the stem (*i.e.* $\frac{1}{2}$ of the way round the stem) from the leaf at the next node. In sedges, and sometimes in hazel and beech, the leaves are *three-ranked*,

the leaf at one node being $\frac{1}{3}$ of the way round the stem from the leaf at the next node above or below; and a thread joining the successive leaves together would wind spirally round the stem *once*, passing *three* leaves in going from any leaf to the next

Photo. Henry Irving.

FIG. 34.—Leafy shoot of Wych Elm and diagram of its phyllotaxis (alternate and two-ranked).

leaf exactly above it. A *five-ranked* arrangement (Fig. 35) is perhaps most common of all; in such cases a thread joining successive leaves would wind spirally round the stem *twice*, passing *five* leaves in reaching one exactly above the first.

These facts are briefly expressed by saying that the phyllotaxis of the iris is $\frac{1}{2}$, that of a sedge is $\frac{1}{3}$, that of a rose, wallflower

or oak $\frac{2}{5}$. The fraction evidently specifies the "angle of divergence" of successive leaves. Thus between one iris leaf and the next there is (as seen in plan) an angle of $\frac{1}{2}$ of 360°, *i.e.* 180°; between successive leaves of a sedge $\frac{1}{3}$ of 360°, *i.e.* 120°; of a rose $\frac{2}{5}$ of 360°, *i.e.* 144°. A phyllotaxis of $\frac{3}{8}$ is found in daisy and plantains.

Leaf mosaic.—Each method of leaf arrangement succeeds in preventing the leaves from overlapping too much, and thereby depriving each other of the supply of light necessary for their work. Thus, even where leaves are closely clustered together (in rosettes against the ground or near the tips of twigs), the lower leaves have usually the longer stalks, so that their blades are not shaded by the upper leaves (Fig. 133). Crowded leaves usually turn until their leaf-blades fit more or less exactly between neighbouring leaves, so that each gets as full a share of light as is possible in the circumstances. It is easy to find examples in which, by different lengths and angles of leaf-stalks, suitable sizes and shapes of leaf-blades, and other features, the foliage of a plant forms a **leaf mosaic** which, while leaving few or no gaps through which light may pass unintercepted, secures for almost every leaf a useful share of illumination (Figs. 34 and 330).

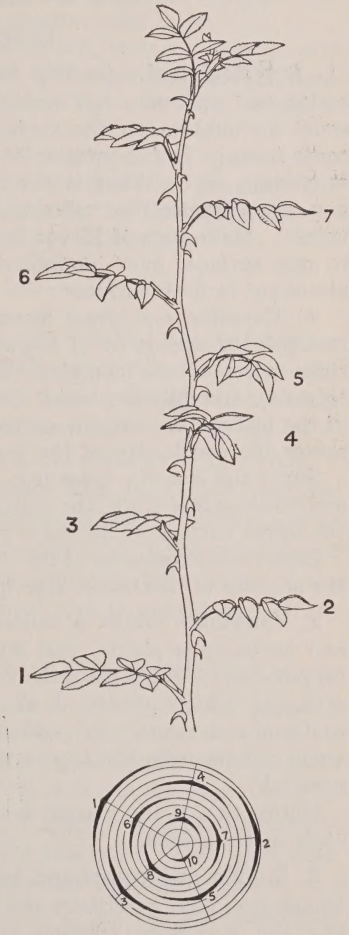


FIG. 35.—Shoot of Rose, with five-ranked leaves (after Avebury), and diagram of its phyllotaxis ($\frac{2}{5}$). (After Strasburger.)

7. THE FORMS OF LEAVES.

PRACTICAL.

1. A typical leaf.—(*a*) Dip various fresh leaves into recently boiled and still very hot water, and look for the appearance of small air-bubbles on the surface of the leaf. Where did they come from? Is the interior of the leaf solid or spongy? Does it contain air? What is the action of heat upon air? Have you any evidence that the skin of the leaf is perforated by small holes? Make lists of leaves in which such holes seem restricted to one surface, more abundant on one surface, about equally abundant in both surfaces.

(*b*) Examine and draw leaves of lesser celandine and marsh marigold in spring, or of hogweed in summer, and identify the three parts of the complete leaf: (i) *blade* (lamina), (ii) *stalk* (petiole), and (iii) the broad sheathing *leaf-base* at the lower end of the leaf-stalk. See the corresponding parts of a dock leaf, and notice the peculiarity of the leaf-base.

Study the leaf of a grass (*e.g.* maize, wheat), note the absence of any obvious leaf-stalk, the split leaf-base, and the scale (*ligule*) on the upper surface of the lower end of the leaf-blade.

Leafy side-extensions of the leaf base are called *stipules*. Study the stipules of hawthorn, rose, pea, beech.*

2. Venation.—Make a collection of leaves of common trees and herbaceous plants, and study the three types of venation: (*a*) *parallel*, in which the main veins run side by side; (*b*) *reticulate pinnate*,† which possess a midrib with side branches dividing to form a network; (*c*) *reticulate palmate*,‡ in which the main veins radiate from the top of the leaf-stalk and divide to form a network.

Notice that if the margin is indented or lobed, a vein supports each tooth or lobe.

3. Simple and compound leaves.—Study examples of pinnate leaves (*e.g.* oak, hawthorn and dandelion) and of palmate leaves (*e.g.* ivy, sycamore, meadow buttercups), of which the blade is cut into so deeply as almost to be divided into separate leaflets.

* Beech stipules fall off immediately after the leaf has unfolded.

† Latin, *reticulum*, a little net; *pinna*, a feather.

‡ Latin, *palma*, the palm of the hand.

With such " intermediate " pinnate leaves compare the *compound* pinnate leaves of ash, rowan, acacia, rose, vetch, etc., and with the " intermediate " palmate leaves compare the *compound* palmate leaves of horse chestnut and lupin.

Compare a single compound leaf of ash, rowan or acacia with a leafy branch of privet. By what differences may a compound leaf be distinguished from a twig bearing a number of simple leaves ?

4. Leaf shapes and margins.—Mount your leaf specimens in a book, and against each leaf write the name of the plant and the type of venation as well as the shape of the blade and the character of the margin as given on pp. 52 and 53.

The parts of a leaf.—The flat part—called the **leaf-blade** or *lamina*—in which the work of an ordinary leaf is done, is usually attached to the stem by a **leaf-stalk** or *petiole*, though the leaves of many plants are stalkless, and are then said to be *sessile*. Beginners have a tendency to refer to a leaf-stalk as a " leaf-stem ; " this term only leads to confusion and should be avoided carefully. The stem-end of a leaf-stalk often widens out to form a well-marked **leaf-base**, which may take the form of paired outgrowths, called *stipules* (Figs. 41 and 43). The forms of the blade, stalk and base of the leaf must now be considered in turn in more detail.

The leaf-blade.—The all-important part of the leaf is the green interior. This (as Expt. 1, *a*, p. 50, shows) is not solid, but spongy in nature, so that a fairly free circulation of air through it is possible. The **green material** which manufactures the plant's food—being generally spread out in thin plates in the form of leaves—obtains a better supply of light than would otherwise be possible. When leaves take some other form than that of plates, it is because of special circumstances in the conditions in the plant's life (pp. 85 and 219). The green material is prevented from drying too quickly by being covered with a thin transparent skin, called the **epidermis** of the leaf. The **veins**, which are left as a " skeleton " for some time after the epidermis and the enclosed green tissue of a dead leaf have rotted away, are very important, for each vein consists essentially of a bundle

of minute pipes or *vessels*, lying side by side, through which watery solutions pass to and from the leaf. For this reason, leaf-veins are often spoken of as **vascular bundles**. They are continuous with vascular bundles which run lengthwise through the stem and root. It is through vessels of the veins or bundles that the soil-water taken up by the roots reaches the leaves, and that the food made in the leaves passes away for distribution to the rest of the plant.

For the making of food, air as well as soil-water must be supplied to the leaf. This air passes into the leaf through minute holes called *stomata*,* which perforate the air-tight and water-proof skin or epidermis.

The **venation** (arrangement of the veins) of a leaf is distinctive. In monocotyledons (herb Paris, arum and black bryony (Fig. 182) are exceptions) the main veins lie **parallel** to each other (Figs. 132, 159 and 302). In dicotyledons they almost invariably form an obvious network (reticulum), and such leaves are said to be

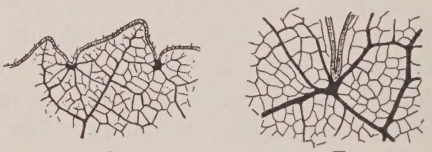


FIG. 36.—" Gussets " at margins of the indentations of leaves (*A*) of the Elm, (*B*) of the Sycamore, showing their relation to the vascular network, and to the mechanically strengthened margin. (×9.) (After Bower.)

reticulate or net-veined. In net-veined leaves the network may be either (1) *pinnate*, when there is a distinct midrib from which secondary veins arise at the sides (Figs. 34 and 39), as the barbs of a feather (*pinna*) spring from the shaft; or (2) *palmate*, when the main veins radiate from a common point at the top of the leaf-stalk, as the fingers of a hand radiate from the palm (Figs. 33 and 45). The large veins so far mentioned branch in their turn to form a fine mesh of veins (vascular bundles) throughout the leaf-blade (Fig. 36). In many dicotyledons a distinct line of veins runs round the leaf near the edge, and so—like the hem at the edge of a flag—protects it from being frayed or torn by the wind. Fig. 36 shows how the danger of the tearing of notched margins is obviated.

* Greek, *stoma*, a mouth (plural, *stomata*).

If the **margin** of the leaf-blade forms a continuous curve (*e.g.* privet), it is said to be *entire*; if simply notched like a saw (*e.g.* nettle, deadnettle, sweet chestnut), *serrate*; if the "saw teeth" themselves are notched (*e.g.* elm), *biserrate*, *triserrate*, etc.; when the teeth are very pronounced (*e.g.* dandelion), *dentate*; if the teeth are stiff and sharply pointed (*e.g.* holly), *spiny*; the margin of an oak leaf is *lobed*; that of ground ivy, *crenate*; young beech leaves are said to be *ciliate*, because they are fringed by fine, silky hairs.

When leaves are toothed or lobed in this way, it may usually be noticed that one of the larger veins runs up the middle of each projection. In other words, the bays or notches in the outline are between the larger veins.

The shapes of leaf-blades.—The thin flattened blades of leaves are usually of a more or less modified oval shape. If we consider *oval* (**widest a little below the middle**) to be the typical form (*e.g.* box) we can suppose the others to be related to it as follows: The *ovate* leaf (the commonest shape) differs from the oval in having pointed ends (beech); *lanceolate* differs from ovate in being proportionately longer (wallflower, white willow); a *linear* leaf is longer still and has parallel edges (grasses); an *acicular* (needle-shaped) leaf is relatively still longer, and is as thick as wide (pine, larch); a *cordate* leaf (lesser celandine) has the conventional heart-shape, thus differing from the ovate leaf only at the stalk end; a *reniform* (kidney-shaped) leaf is like a cordate leaf rounded at the tip (ground ivy); a *sagittate* (arrow-head shaped) leaf is like a cordate leaf with each side prolonged to a point instead of being rounded (arrow-head).

When the leaf is **widest above the middle**, and thus up-side-down as it were, in comparison with the foregoing shapes, the prefix *ob* is added to the terms, giving *obovate*, *obcordate*, etc. The *spatulate* shape (common where leaves form a rosette) may be supposed to be derived from the obovate by rounding of the tip (stock, primrose, oak). The term *elliptical* is self-explanatory. *Orbicular* leaves (*e.g.* garden nasturtium, lupin, water lily, etc.) are more or less circular. *Hastate* (spear-head shaped, *e.g.* sheep's sorrel) and *runcinate* (*e.g.* dandelion) are shapes easily recognised but not simply described in words.

The tip or **apex** of a leaf, if pointed, is *acute* or *obtuse* according to the size of the angle. If not pointed it is either *rounded* or *notched*.

In many cases the shape of the leaf seems to be determined by the **vernation**, that is the way in which it is folded or rolled in the bud stage, when close packing is a great advantage

by saving room and lessening evaporation. Lobes or notches in the margin often save the leaf from tearing as it straightens out when the bud unfolds (*e.g.* oak). The method of folding in its turn depends largely on the arrangement of the veins. It may be

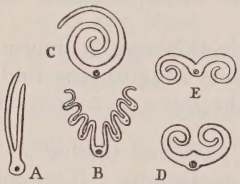


Fig. 37.—Types of Vernation (cross sections of young leaves.) The midrib (lower surface) is shown by a dot. *A*, *Conduplicate* (*e.g.* oak, elm, cherry); *B*, *Plicate* (*e.g.* sycamore, beech); *C*, *Convolute* (*e.g.* plum, blackthorn); *D*, *Involute* (*e.g.* apple, pear, poplars); *E*, *Revolute* (*e.g.* rhododendron, docks).

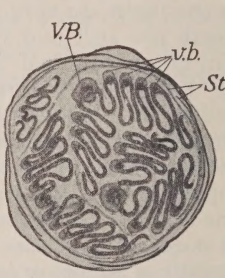


Fig. 38.—Photomicrograph of cross section of resting leaf-bud of Beech. (× 8.) *V.B.*, midrib of leaf; *v.b.*, lateral veins of leaf. *St.*, bud scales (stipules). (T. D. Tuton Hall.)

studied in cross-sections of buds (Figs. 38 and 117), and, better still, in half-opened buds. Some common types are shown in Fig. 37.

Simple and compound leaves.—In different leaves all stages may be found, from slight notching of the margin, to indentations extending to the midrib and so cutting up the blade into separate leaflets. Thus we distinguish between simple leaves, in which the blade is in one piece, and compound leaves, the blades of which consist of separate leaflets. A deeply indented pinnate leaf like that of the oak, which is nearly but not quite compound, is described as *pinnatifid*; the corresponding "intermediate" condition in palmate leaves (*e.g.* sycamore) is called *palmatifid*.

Compound leaves are described as *pinnate* if the leaflets are arranged at the sides of the midrib (*e.g.* rose, rowan, ash) and *palmate* if they arise together at the top of the leaf-stalk (*e.g.* horse chestnut, lupin). The differences are plainly related to differences in the venation of the leaf. The leaflets of a pinnate leaf may themselves be divided into smaller separate parts. Such a leaf is said to be *bipinnate*, the leaflets being referred to as pinnae, and the separate parts of the pinnae as pinnules. If the branching goes a stage further, so that the pinnules also are divided, the leaf is *tripinnate* (*e.g.* carrot); many ferns have tripinnate leaves.

The leaflets of compound leaves are of various shapes, described by the terms used for simple leaves, given on p. 53. Their resemblance to complete leaves may cause beginners to be uncertain **how to distinguish a compound leaf from a twig bearing a number of simple leaves.** If it is a twig it will end in a bud, and the leaves it bears will usually have buds in their axils (p. 46). If the specimen is a compound leaf, the apparent " twig " is the

Photo. Henry Irving.

FIG. 39.—Compound pinnate leaf of Rowan. ($\times \frac{1}{2}$.)

midrib ; usually it has a bud in its axil, but does not end in a bud ; it may (Fig. 39) or may not terminate in a leaflet. Also the apparent " leaves " (really leaflets) do not have buds in their "axils." It is useful to compare from this point of view the compound pinnate leaves of rose, rowan, ash, or elder with a twig of Solomon's seal (Fig. 132), weigelia or privet, bearing opposite leaves in one plane ; and the compound palmate leaf of horse chestnut or lupin with a stem or branch bearing whorled leaves.

A compound leaf consisting of three leaflets (*e.g.* clover (Fig. 41), strawberry, wood sorrel, laburnum) is described as *ternate*.

Photo. Henry Irving.

FIG. 40.—Compound palmate leaves of Horse Chestnut.

In many plants of the pea family (p. 259) certain of the leaflets are reduced to such an extent that only the main vein of each persists. This takes the form of a *tendril*, which enables the plant to climb (p. 188). This is well seen in peas (Fig. 43); in this case some compensation for the sacrifice of food-making leaf-blade to make climbing-machinery is obtained by the flattening of the leaf-stalks and the stems, and by the unusual size of the stipules. In the yellow vetchling (Fig. 124) the large and broad stipules are the only

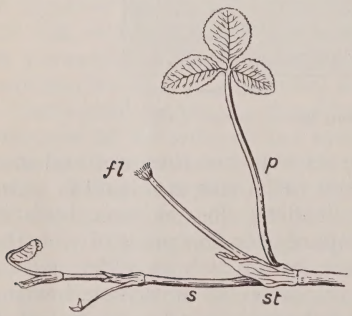


FIG. 41.—Clover. Tip-region of prostrate stem, *s*, bearing leaves and a flowering branch, *fl*, in the axil of the oldest leaf shown; *p*, petiole; *st*, stipules. (After Avebury).

parts of the leaf concerned in food making; the rest of the leaf is represented by a single tendril.

The petiole or leaf-stalk.—The lamina or blade of the leaf is usually joined up to the stem by a leaf-stalk. Where the stalk is absent and the blade is directly attached to the stem, the leaf is said to be *sessile*. The leaf-stalk is mostly fixed to the margin of the blade; but in the garden nasturtium (Fig. 45), pennywort and lupin the stalk is attached to the blade at some distance from the edge, and such leaves are said to be *peltate*.

The petiole is generally a thin simple rod, made up largely of the vascular bundles connecting the veins of the leaf-blade with those of the stem, and stiff enough to hold out the blade. If the leaf-stalk is horizontal or nearly so, so that the weight of the blade is at right angles to the stalk, the vascular bundles (as seen in cross-section of the stalk) together form a trough open above (Fig. 116). If the stalk is nearly or quite vertical, so that the weight of the blade is along the *length* of the stalk, the bundles form an incomplete cylinder (compare the arrangement in stems (p. 167)). The leaf-stalks of "rosette-plants" lying on the ground, which supports the weight of the leaves, have their bundles arranged more or less in a horizontal plane.

Sometimes the leaf-stalk is so much flattened as to be able to take on an appreciable share of the usual work of the leaf-blade. The best example of this in the British flora is the grass vetch, in which the leaf-blade is not present and all its duties are carried out by the flattened leaf-stalk, which has much the appearance of the leaf-blade of a grass. Such a flattened petiole is called a **phyllode**. The flattening of the petiole of the sweet pea (p. 189) is of the same nature, but less marked.

The leaf-base.—The lower end of the leaf-stalk is often enlarged, and is then distinguished as the leaf-base. In its simplest form it is an expansion more or less ensheathing the stem (Ranunculaceae, Umbelliferae). If it reaches quite round the stem so as to form a complete tube, it is called an *ochrea* (dock and sedge families). In grasses (Fig. 113) the sheath formed by the leaf-base is split on the side away from the blade. In the plane, the leaf-base forms a conical cap fitting over and protecting the axillary bud. The protection afforded by the leaf-base to the axillary bud is also obvious in varying degree in very many other plants. In the winter buds of sycamore and horse chestnut, the outer scales themselves consist of the tough bases of leaves which are otherwise undeveloped, as is shown clearly by intermediate stages to be found between these outer scales and the complete leaves in the middle of the bud

(pp. 175 and 431). Such intermediate stages between leaf-bases and complete leaves are particularly well shown in the buds of flowering currant.

FIG. 42.—Flowering shoot of Barberry, with leaves reduced to spines. (After Figuier.)

The underground bases of the foliage leaves of woodsorrel (Fig. 130), hyacinth, lilies (Fig. 145), daffodil, etc., become swollen with a surplus of food during the spring, and when the aerial parts of the leaves have withered, the swollen leaf-bases remain. Such leaf-bases form the greater part of the underground **bulbs**, by means of which many plants survive the winter and resume their growth in the following spring (pp. 204 and 218).

In many plants (ivy, privet, virginia creeper, runner bean, clover, woodsorrel, etc.) the leaf-base forms a kind of cushion called a **pulvinus** (Fig. 44), which, by altering in shape, causes the petiole and blade to move through a relatively large angle, so that the leaf can shift its position according to the direction and intensity of the light. The "sleep-movements" of the leaflets of kidney bean, clover and woodsorrel, etc., are brought about by similar organs of movement at the bases of the stalks of the leaflets (Chap. XIV.). In the gooseberry the leaf-base is spiny, while on certain branches of barberry the whole leaf is reduced to spines (Fig. 42).

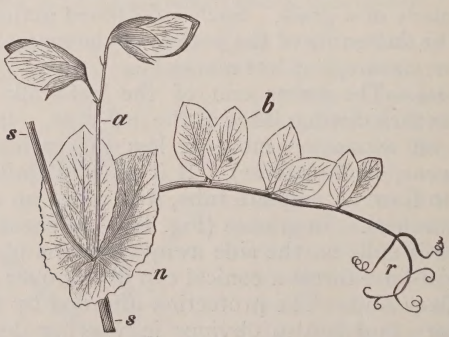


FIG. 43.—Portion of leaf and stem of the common pea, *Pisum sativum*; *s*, stem; *n*, stipules; *b*, leaflets of the compound leaf; *r*, leaflets modified as tendrils; *a*, floral shoot. (½ nat. size.) (After Schenck.)

The most conspicuous of the various modifications of the leaf-base takes the form of a pair of outgrowths called **stipules.**

Typically, stipules are leaf-like ; besides protecting the axillary bud, they supplement the work of the leaf-blade. The large size of the stipules in such plants as the sweet pea, garden pea (Fig. 43) and yellow vetchling, where a part or the whole of the blade has been sacrificed to make tendrils (p. 189), is especially interesting. In many leaves with large stipules, however (*e.g.* pansy), the blade also is large and efficient (Fig. 256). Leaves without stipules are said to be exstipulate.

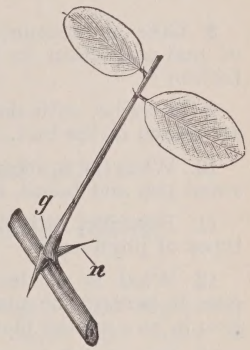


Fig. 44.—Part of stem and compound leaf of *Robinia pseudacacia* ; *n*, stipules modified into thorns ; *g*, pulvinus. (½ nat. size.) (After Schenck.)

Modifications of stipules are not uncommon. In beech, oak, elm, hazel and poplar, the outer *bud scales* which protect the young foliage leaves through the winter (Fig. 32) are stipules of leaves which otherwise remain undeveloped. In the beech, the foliage leaves themselves have large strap-shaped stipules when they emerge from the buds in the spring ; the stipules are soon shed, however, and may be found in countless thousands on the ground of a beech wood in spring (Chap. XX.).

The stipules of Robinia (false acacia) take the form of *spines* (Fig. 44) ; those of the Smilax are modified to form *tendrils.*

EXERCISES III.

1. Of what main parts is a herbaceous flowering plant composed ? State briefly what is the special work of each part.

2. Describe the structure of any net-veined leaf as seen by the naked eye or with a hand lens. Explain the importance of the various features you describe. Describe similarly any one other leaf showing characters different from those of the first. (J.M.B. Matric.)

3. Make a careful drawing of *A*, naming the parts, and write short notes on any features of special interest.

[*A* = piece of stem with leaves of garden pea.] (J.M.B. Matric.)

4. What is a bud ? In what positions on the shoots of flowering plants do buds occur ?

5. Make a large-scale drawing of any named bud as seen in longitudinal section, and label all the parts shown.

6. Make a labelled drawing of specimen *D*; comment on any features of interest. [*D* = seedling of gorse.] (C.S.)

7. Make a good-sized labelled drawing of (1) a typical vegetative bud, (2) the same bud expanded into a shoot. (J.M.B. Jun. Cert.)

8. Give an account, illustrated by sketches, of the methods of bud-protection in British plants. Why do buds need protection? (L.M.)

9. Describe, with sketches, four different ways in which leaves are folded in the bud.

10. What is a stipule? Describe and sketch the stipules of sweet pea and beech, and explain their use to the plant.

11. Describe, with diagrams of named examples, five common types of phyllotaxis.

12. What is a "leaf mosaic," how is it produced, and how does it benefit the plant? Draw an example of leaf mosaic as seen in any named plant.

13. Show by diagrams how you would distinguish (*a*) between a stem and its branch if the branch were the larger; (*b*) between one compound leaf and a twig bearing several simple leaves.

14. Find specimens, or study the illustrations in this book, of the leaves named on p. 53, and make diagrams illustrating the descriptive terms mentioned.

CHAPTER IV.

LEAVES: THE MAKERS OF FOOD.

8. LEAVES AND THEIR SUPPLY OF LIGHT.

PRACTICAL.

1. Presence of carbon in all plant tissues.—Heat separately in a combustion tube small pinches of starch and sugar, as well as pieces of stem, leaves, roots, flowers and seeds which have been previously dried in an oven, and notice the liberation of black charcoal (carbon) in each case.

2. To test for starch in leaves.—Pluck a leaf * which has been exposed to bright light for some hours immediately before, and boil it in water at once for two minutes, transfer it to a beaker, cover it with methylated spirit and leave it for some hours. If delay is inconvenient, heat the beaker by putting it into the hot water (previously removed from the fire or gas flame, because the vapour of the spirit is inflammable). Notice that the green colouring matter (chlorophyll) of the leaf is dissolved out into the spirit (because it is soluble in alcohol), leaving the leaf white or nearly so. [Is chlorophyll soluble in water ?] Pour off the spirit, rinse the leaf with water, and then *cover* it with iodine solution. If it contains starch it slowly turns blue or dark purple.

3. How to obtain a living leaf free from starch.—Cut off a leafy twig, or several leaves, and keep them in the dark over night with the twig or stalks dipping in water to keep the leaves alive and healthy; or put whole plants (growing in pots) into the dark. After twelve hours or more, kill one leaf by

* Almost any thin-skinned and smooth dicotyledon-leaf or leaflet is suitable for these experiments. Elder leaflets are excellent and in towns often more easily available than others.

boiling, and test it for starch as in Expt. 2. If no blue colour is formed with iodine solution, the other leaves of the set, which are still alive, may be assumed to be also **free from starch**, and may be used for Expts. 4 and 5 below, and for Expt. 2 (p. 67). Throughout all such experiments the twigs or stalks of the leaves should dip in water.

4. Is light necessary for starch formation in leaves ?—(*a*) Take two leaves freed from starch by being kept in the dark. Expose one to bright light for several hours in the usual manner, and let the other remain in the dark for the same time. Then kill both and test them for starch.

(*b*) Attach a small piece of opaque paper or a slice of cork to a strip of transparent Kodak film,* and pin this on the *upper* surface of a starch-free leaf (Fig. 45). Support the leaf loosely on black velvet (to avoid reflection of light from below without depriving the lower surface of air) and expose it to bright light for some hours with its stalk dipping in water. Kill and test for starch. Is any part of the leaf still destitute of starch ? Was this part deprived of *air* to a greater extent than neighbouring parts ? Was it deprived of *light* to a greater extent ? In what respects was it treated differently from the rest ?

5. Is chlorophyll necessary for starch formation in leaves ?—Apply the starch test to different " variegated " leaves (parts of which are not green) of (*e.g.*) elder, dogwood, garden nasturtium, laurel, etc., immediately after they have been exposed to bright light for several hours.

Leaves as makers of carbonaceous food.—Leaves must now be considered in relation to **their most important function** : the manufacture of the plant's food from materials which in themselves are not food. The foods made by plants are of various kinds—sugars, starch, proteins, etc.—but they all contain *carbon* as an essential constituent. No matter what part of a plant be strongly heated, without being allowed to catch fire, some charcoal (which is impure carbon) will separate. Moreover, the amount of carbon in a plant increases as the plant grows in size. More charcoal can be obtained from a full-grown oak tree than from a seedling oak.

* Obtained by soaking a spoiled negative in water and rubbing off the softened gelatine.

What is the source of this carbon? It must come either from the soil or from the air. Ordinary soil certainly contains carbon in various forms (p. 109), but it is possible to grow a young plant—say a young oak—successfully for years with its roots not in soil, but in a solution (such as that described on p. 116) which does not contain carbon; yet the amount of carbon in the plant increases steadily notwithstanding. In such a case it is plain that the carbon can only come from the air. Air, however, is a mixture of gases, one only of which contains any carbon; this constituent is *carbon dioxide*, which forms 0·03 to 0·04 per cent. of fresh country air. It appears highly probable, therefore, that in general the carbon dioxide of the air is **the source of the carbon** which forms so essential a part of the food substances manufactured by plants. This conclusion seems inevitable, though the evidence just given is merely indirect. It can, however, be proved directly (p. 70).

Recognition of starch in leaves.—No one knows exactly what happens in the process by which such relatively simple materials as carbon dioxide and water are combined in the leaf to make sugar and then starch, though the main stages have now been traced (p. 72). It is possible, however, by a number of interesting experiments, to find out what *conditions* are necessary for it. Fortunately, starch is easily recognised when present in leaves, by means of the iodine test (p. 61), so that we can find by trial what are the conditions under which starch is formed in leaves. Obviously, for this we must experiment with leaves free from starch.

A green leaf, removed from any ordinary dicotyledon,* after exposure to several hours' bright light, *killed at once* by boiling in water for a minute or two, and decolourised by alcohol, turns blue when soaked in iodine solution, and is thus proved to contain starch. If, however, a similar leaf, instead of being killed, is kept alive in the dark for twelve hours or longer (the time depending on the kind of leaf and other circumstances) and then killed and tested with iodine, the starch which (as the previous experiment shows) it must have contained when put in the dark

* In many monocotyledons starch is not formed, the process stopping at the sugar stage.

has disappeared, for no blue colour is formed. This preliminary work shows that **to obtain healthy leaves free from starch** we merely need to keep them in the dark for a certain length of time.*

Using such leaves, we are in a position to find out whether any particular condition is or is not necessary for starch formation in a leaf.

Light necessary for carbon assimilation.—For example, having already found evidence (p. 43) that a good supply of light is of great importance to plants, we are naturally led to inquire whether light is necessary for the formation of starch in a leaf. If so, the apparent efforts made by leaves to reach a well-lighted position acquire a new significance. To test the correctness of the surmise we may take two healthy *starch-free* leaves and expose one to bright light for several hours, but keep the other in the dark. In *all other respects* the leaves must, of course, be under similar conditions. The iodine test after killing shows that the leaf exposed to light has formed starch in the meantime, but that the leaf deprived of light, but in all other respects treated similarly, still remains destitute of starch. Such an experiment proves definitely that light is necessary for the formation of starch in the leaves of a plant growing under ordinary conditions.

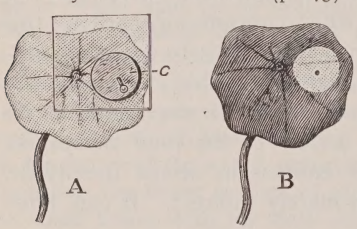


FIG. 45.—*A*, Tropaeolum leaf (freed from starch), on the *upper* side of which has been pinned a transparent sheet of celluloid bearing a slice of cork, *C*.

B, the same leaf tested for starch with iodine solution, after exposure to bright light for an hour whilst lying on black velvet. The part shielded from the light remains bleached; all the rest of the leaf has turned blue. (×⅔.)

Fig. 45 illustrates a simple device by which part of a healthy starch-free leaf can be shielded from light whilst receiving air as freely as neighbouring parts which are exposed to light. The failure of only the shaded part to make starch in these circumstances is a striking proof of the need for light.

The process by which a leaf builds up sugar and starch in this way is known as carbon assimilation or **photosynthesis**. The latter

* It should be noticed that it does not tell us anything whatever about the conditions under which starch is *formed* in leaves.

term, which means "putting together by means of light," is the better, because it emphasises the part played by light in the manufacture of carbonaceous food.

Light is not a substance, and therefore does not furnish any *material* for the manufacture of food. What it contributes to the process is energy, that is, the driving power of the peculiar "machinery" which does the work. Now, white light is a combination of light rays of different kinds, which show as a band of colours, called the spectrum, when a beam of sunlight is passed through a prism (a wedge-shaped block) of glass (Fig. 46). They are, in order, red, orange, yellow, green, blue, indigo and violet. It is easy to understand that the different parts of the spectrum, which vary so much in colour, may also differ enormously in suitability for "driving the machinery" of food-making. Indeed, experiments show that starch formation may go on as vigorously in leaves supplied with **reddish light** only as in ordinary white light; while leaves in light belonging to the other end of the spectrum (*i.e.* blue, etc.) have practically no power of making starch in this way.

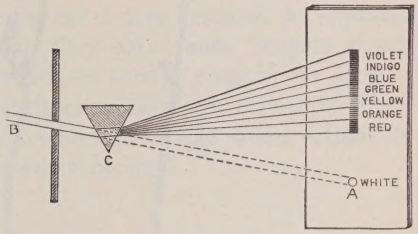


FIG. 46.—Experiment to show that white light is a mixture of colours.

Chlorophyll necessary for photosynthesis.—The colour of the light absorbed by the leaves is plainly a matter of importance, and this explains why leaves are so constantly green. Any green object is green because it absorbs the part (*e.g.* red) of the light which is not green, and reflects or transmits the green which we see.

The chlorophyll—the green colouring matter of the leaf—is thus useful because it absorbs from white light the exact colours which supply the living part of the leaf with the sort of energy needed for the work of photosynthesis, and gives out the colours which are useless. It is not surprising, therefore, to find that when "variegated" leaves of ivy, laurel, elder, etc. (often grown in gardens for their ornamental appearance), are

tested in the usual manner (p. 61) immediately after some hours' exposure to bright light, starch is found only in the parts which were green, but is absent from the parts which were white.

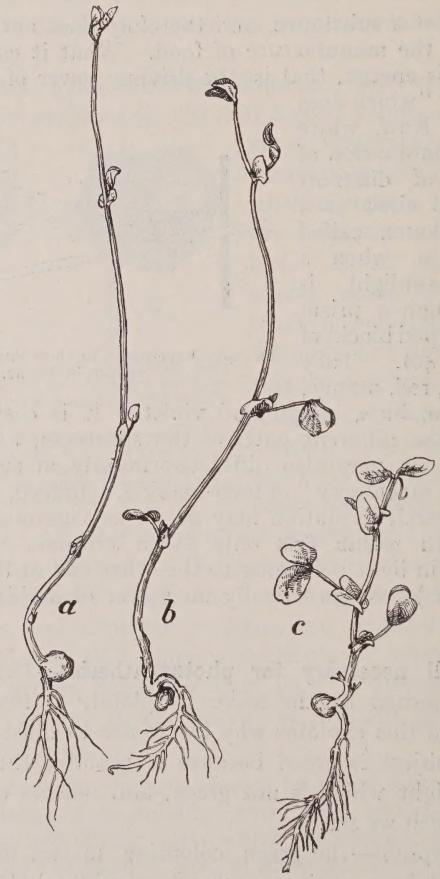


FIG. 47.—Peas grown 6 days (*a*) in darkness, (*b*) in about $\frac{1}{8}$ light, (*c*) in full light in a greenhouse. (After Duggar.)

Etiolation.—To keep leaves in the dark for one or two days makes no appreciable difference to their colour, but if they are deprived of light for much longer than this, the green colour gradually gives place to a pale sickly yellow, and the shoots

grow long and straggling. This condition is called etiolation (Fig. 47, *a*). If seeds are germinated in darkness the young leaves are small, and pale yellow instead of green,* and if light is withheld the plant dies as soon as the seed-food is exhausted, since it is unable to manufacture any food for itself. The pale colour of etiolated leaves is due to lack of chlorophyll, since this colouring matter usually needs light for its formation. If the mischief has not gone too far it may be cured by exposure of the leaves to light, when they once more become green. Certain food vegetables (sea-kale, celery, potato, cos lettuce, etc.)—which when grown exposed to light are injurious, bitter or tough—become wholesome and palatable when artificially etiolated by earthing-up or other means.

9. LEAVES AND THEIR SUPPLY OF AIR.

PRACTICAL.

1. The interior of the leaf communicates with the air.—Repeat Expt. 1, *a* (p. 50).

2. Is air necessary for starch formation in leaves?—(*a*) Smear half of a starch-free leaf with castor oil † on both sides, and then expose the leaf to bright light for several hours. Kill the leaf and test for starch as in Expt. 2 (p. 61).

(*b*) Confirm by doubling a piece of transparent Kodak film over part of a starch-free leaf (fastening it in position with a wire paper-clip), exposing the leaf to several hours' bright light, and then testing for starch.

(*c*) Repeat the experiment with the film covering part of the *upper* surface only. Does the result show that the leaf can obtain its necessary air by the lower surface only?

3. Which part of air is necessary for starch formation in leaves?—Fit a large wide-mouthed glass bottle with a cork or rubber plug through which passes a glass tube bent as in Fig 49. Pack

* A few exceptions to this are known. Pine seedlings germinated in the dark have green cotyledons, and sycamore embryos are green even in the fruit.

† Better than vaseline for the purpose, because soluble in alcohol (*e.g.* methylated spirit). Castor oil has no injurious effect on leaves beyond blocking up the stomata (p. 52).

the bend of the tube loosely with pieces of soda lime, and in the bottle place a small jar containing lumps, or a strong solution, of caustic soda. (Both soda lime and caustic soda absorb carbon dioxide readily, but not oxygen or nitrogen.) Now put in the bottle a small plant, or a leafy twig or leaves, previously kept in the dark to free the leaves from starch. Make all joints tight, soaking the cork in melted paraffin if necessary to ensure this; expose the whole to bright light for a few hours, and then test a leaf for starch (p. 61). Remove the soda-lime tube and the caustic soda, fill the same bottle with ordinary air (by filling it with water and then pouring out the water), expose the remaining leaves to light in it, and again test a leaf for starch.

4. How the air is affected by green leaves.—(*a*) *Leaves exposed to light.*—Fit up the apparatus shown in Fig. 48. A tap funnel may be used instead of *f*. Pack the bottle loosely with green leaves (*e.g.* elder) and blow through the funnel for about a minute, to replace the air by expired air from the lungs. Collect a sample of the air now in the bottle, by putting the end of *d* under a jar full of water inverted in a pneumatic trough and continuing to blow. Find out if the sample turns lime-water milky, and if it will support the combustion of a taper. Next plug the end of *d*—if a tap funnel is used, turn off the tap—and place the apparatus in bright light for several hours. Now collect over the pneumatic trough a sample of the air in the bottle (by removing the plug and pouring water through the funnel). Does this air turn lime-water milky? Does it support the combustion of a taper? Has the amount of (*a*) carbon dioxide, (*b*) oxygen, increased or decreased during exposure of the leaves to light?

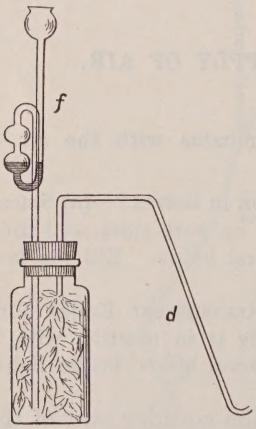


FIG. 48.—Experiment to show the changes which green leaves, exposed to light, cause in the composition of the surrounding air.

(*b*) *Leaves in darkness.*—Remove the leaves and fill the bottle with ordinary air. Pack loosely with leaves again, plug the delivery tube, close the funnel, and keep the apparatus in the dark. After twenty-four hours or less, collect and test, as before, a sample of the air in the bottle. How does it differ in properties

from ordinary air, such as was in the bottle at the beginning of the experiment?

The leaf's air-supply.—It may be readily shown (Expt. 1, *a*, p. 50) that the green interior of a leaf is in free communication with the surrounding air. When a leaf is held below the surface of hot water, tiny bubbles of air appear on the surface of the leaf-blade. Usually the bubbles are much more numerous on the lower surface, and may be restricted to this surface; but in some cases they form on both surfaces. It is clear that the air bubbles must have come from the interior of the leaf (for they do not appear on, say, a sheet of tinfoil treated in the same way), and that the spongy interior of the leaf must be covered by a skin pierced by holes through which part of the internal air (expanded by the heat) is expelled. These pores are called **stomata.*** In some plants (*e.g.* marsh marigold) the stomata may be demonstrated by holding the stalk of an uninjured leaf between the lips, placing the leaf-blade in water, and blowing, when streams of fine air bubbles issue from the surface. This experiment further shows that there is complete communication between the air cavity in the stalk of the marsh-marigold leaf and the stomata on the surface of the blade, through the small air-chambers in the leaf-blade.

By carefully tearing various leaves across, it is easy to strip off small pieces of the colourless skin or epidermis. With a good hand-lens the positions of the stomata (the existence of which was revealed by the experiments just referred to) can often be seen as fine dots on such a piece of lower epidermis spread out in water on a glass slide and held up to the light. The details, however, cannot be made out without the use of a microscope (p. 103).

Air necessary for photosynthesis.—The indirect evidence mentioned on p. 63 gave us good reason for believing that a supply of air is necessary for starch formation in leaves. To prove positively that this is so, we may take a living leaf we know to be free from starch, exclude the air from part of it by some means (*e.g.* smearing it with castor oil, Expt. 2, p. 67) which

* Greek, *stoma*, a mouth (plural, *stomata*).

will not also deprive it of light—leaving the remaining part of the leaf untreated and therefore able to get both air and light—and expose the whole to bright light under conditions as natural as possible. When the leaf is tested afterwards in the usual way, the untreated portion is found to have formed starch; while the part which was deprived of air, but in all other respects was normal, has not formed starch. For photosynthesis, therefore, a supply of air is indispensable.

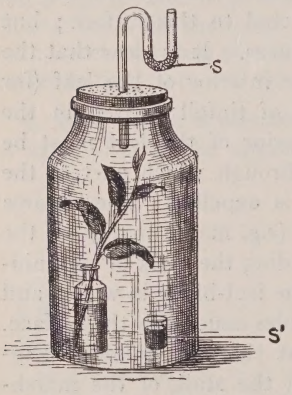


FIG. 49.—Experiment to prove that leaves do not make starch unless the air with which they are supplied contains carbon dioxide. *S*, tube containing lumps of soda lime: *S'*, jar containing a solution of caustic soda.

Knowing that air is a mixture of nitrogen, oxygen, argon and carbon dioxide, we naturally follow up this result by an experiment to discover which particular constituent of the air furnishes material for photosynthesis. We have already (p. 63) found reason to suppose that it is the **carbon dioxide**. We can check this conclusion by trying the effect of supplying leaves with air which contains no carbon dioxide, but in all other respects is identical with ordinary air (Fig. 49). In such circumstances it is found (Expt. 3, p. 67) that they cannot make starch. The same leaves, when again supplied with air containing carbon dioxide, are able to make starch as before.

Effect of photosynthesis upon the surrounding air.—It seems probable, from the above, that during photosynthesis the amount of carbon dioxide in the air surrounding leaves must be diminished. The proportion of carbon dioxide in ordinary air is, however, so small (not more than 0·04 per cent.) that its loss during photosynthesis is not easily shown by a simple experiment.

If, however, leaves can be surrounded by air containing a much larger proportion of carbon dioxide than this, we may expect their activity to bring about a marked difference in the composition of the air. We can, for example, supply them with air breathed out from the lungs. Such expired air differs

considerably from ordinary air in the proportion of both carbon dioxide and oxygen present, as is seen by the comparative percentage compositions given below:

	Nitrogen and Argon	Oxygen	Carbon dioxide
Ordinary air - -	79·00	20·06	0·04
Expired air - -	79·50	16·50	4·00

Expired air breathed through a tube into clear lime water causes the lime water at once to become very milky, whereas ordinary air passed through lime water causes a milkiness much more slowly. A lighted taper plunged into a jar of expired air is at once extinguished, because the proportion (16·5 per cent.) of oxygen present is not sufficient to support combustion. On the other hand, ordinary air, as everyone knows, does contain sufficient oxygen to support the combustion of a taper. The two kinds of air thus contrast very strongly with each other in properties.

By means of experiment 4, *a*, p. 68, it is easy to show that green leaves, in bright light, quickly change expired air to such an extent that (1) carbon dioxide can no longer be detected in it by the lime-water test; (2) the proportion of oxygen in the mixture has increased enough to allow a taper to burn in it. We find, then, that photosynthesis, by aerial leaves, is accompanied not only by the absorption of carbon dioxide, but also by the liberation of oxygen.

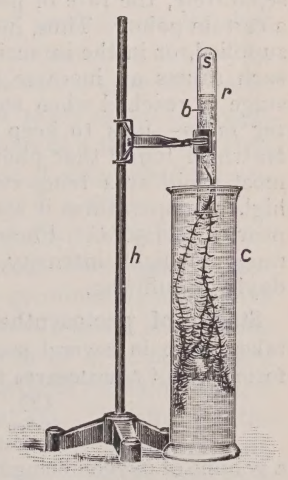


Fig. 50.—Evolution of oxygen from freshly cut ends of pond-weed (*Elodea canadensis*) in sunlight. (After Noll.)

Photosynthesis by aquatic plants.—A well-known experiment proves that the leaves of aquatic plants behave similarly. *Elodea* (American pond-weed) and other water-weeds, in bright light, give off bubbles of gas which may be collected by the simple arrangement shown in Fig. 50. When a glowing splinter of wood is

plunged into such gas it bursts into flame again, showing that the gas contains a large proportion of oxygen. But if in this experiment water is used which has been recently boiled (to expel its dissolved carbon dioxide) and cooled to the same temperature as before, no oxygen is evolved.

Conditions necessary for photosynthesis.—We may therefore say as a result of our experiments, that the *special* conditions necessary for carbon assimilation are:

(1) a supply of carbon dioxide,
(2) the presence of chlorophyll,
(3) a sufficient intensity of light.

With these special conditions should be included, of course, the *general* conditions for healthy plant life, such as a suitable temperature, an adequate supply of water and air to the roots, etc.

Experiments have shown that when the conditions are varied separately, the rate of photosynthesis varies accordingly, up to a certain point. Thus, increase in the amount of carbon dioxide supplied, or in the intensity of the light, or in the temperature, each causes an increase in the rate of photosynthesis until a stage is reached when some condition—hence called the *limiting factor*—fails to keep pace with the increasing rate. Miss Matthaei found that photosynthesis in a cherry laurel leaf was most rapid at a temperature of about 37° C. At lower and higher temperatures it was much slower, and ceased altogether near 0° and 50° C. Photosynthesis is possible with a very wide range of light intensity, as little as one-twelfth of ordinary daylight sufficing.

Stages of photosynthesis.—It appears that photosynthesis takes place in several stages, the first of which is probably the formation of **formaldehyde** thus:

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} = \underset{\text{formaldehyde}}{CH_2O} + \underset{\text{oxygen}}{O_2},$$

a volume of oxygen being liberated equal to that of carbon dioxide used. Some of the active formaldehyde thus produced unites in the leaf with nitrogen compounds (obtained by the roots from the soil—Chap. V.) to form **proteins**. The molecules of the remaining formaldehyde tend, as the solution becomes more concentrated, to unite in sixes to form the sugar called **glucose**:

$$\underset{\text{formaldehyde}}{6CH_2O} = \underset{\text{glucose}}{C_6H_{12}O_6},$$

and the molecules of glucose in their turn to unite in pairs to form **cane sugar** and water :

$$\underset{\text{glucose}}{2C_6H_{12}O_6} = \underset{\text{cane sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O}.$$

There is reason for considering that cane sugar and not starch is the true end-product of photosynthesis, and in monocotyledons the process often stops at the sugar stage.

Accumulation of the cane sugar in solution beyond a certain concentration in the cells of the leaf hinders the continuance of photosynthesis, but if the soluble sugar can be converted into the insoluble carbohydrate **starch**, as it is in most dicotyledons, it is in effect laid aside as soon as formed, and "clogging of the machinery" is avoided :

$$\underset{\text{cane sugar}}{C_{12}H_{22}O_{11}} - \underset{\text{water}}{H_2O} = 2\underset{\text{starch}}{C_6H_{10}O_5}.$$

Leaves of the water-weed *Elodea*, put in the dark until they are free from starch and then kept (still in the dark) in a weak solution of glucose (grape sugar) will form starch.

Leaves and respiration.—When leaves are kept *in the dark* they gradually absorb oxygen from the air and give out carbon dioxide. In a comparatively short time leaves kept in a bottle in the dark abstract from the air in the bottle so much oxygen that it no longer supports the combustion of a taper, and they add to it so much carbon dioxide that it immediately turns clear lime-water very milky (see Expt. 4, *b*, p. 68).

Air surrounding germinating seeds is similarly affected (pp. 24 and 25), and we might substitute opening flower-buds or leaf-buds, or pieces of fresh stem or root for germinating seeds, with the same result : in each case oxygen is absorbed and carbon dioxide is given off. Moreover, Experiment 4, p. 68, showed that whilst in the human lungs air undergoes the same change.

All these are the result of **respiration** (p. 27). Its effect on the air is the precise opposite of that caused by photosynthesis, and the two processes must be distinguished most carefully from each other. Respiration always **involves a loss** of organic material which, as in ordinary combustion, unites with oxygen to form carbon dioxide and water, energy being liberated at the same time. Photosynthesis, on the contrary, is food manufacture, resulting in an *increase* of plant material; it is *in no sense* a special method of breathing.

Respiration takes place in all active parts of a plant and at all times—in the light as well as in the dark—and furnishes the energy for their life processes. In the light, however, the respiration of leaves is *masked*, for they are then perhaps thirty times more active in photosynthesis than in respiration; the net result is, therefore, that leaves in light increase the amount of oxygen in the surrounding air and decrease the amount of carbon dioxide.

In the living plant, oxygen reaches the centres of activity through **air channels**, which occur between the cells, not only in the leaf-blade but in the leaf-stalk (p. 69), the stem and the roots, and are in communication with each other and the outside air (pp. 128, 145 and 293). The carbon dioxide formed in respiration and not used for photosynthesis makes its way to the exterior through the same channels.

EXERCISES IV.

1. From what source do green plants obtain their supplies of carbon? How could you show that carbon is contained in plants? (O.J.)

2. If a number of leaves of different kinds are plucked in the afternoon of a warm sunny day, boiled in water, soaked in alcohol till their green colour is removed, and then put into a solution of iodine, some turn coal black, some dusky, while others retain a yellowish tint. Account for this as fully as you can, and include in your answer an explanation of the procedure outlined in the question. (J.M.B., Hr. Sch. Cert.)

3. Describe carefully experiments by which you would prove that (1) light and (2) carbon dioxide are necessary for starch formation. (J.M.B., Hr. Sch. Cert.)

4. In what circumstances is starch formed in a green leaf? How could you demonstrate its presence? How does the plant dispose of the starch so formed? (O.S.)

5. How could you show:

(*a*) That the presence of carbon dioxide in air is essential for the production of starch in a leaf?

(*b*) That carbon dioxide is absorbed by a green plant in the presence of light? (J.M.B. Matric.)

6. It was once thought that the carbon in plants was obtained from the soil. Describe in detail experiments which show the real source of this carbon. (Cert.)

7. Explain carefully where green plants obtain carbon dioxide for photosynthesis, how it enters, where it is dealt with, and what is made from it, giving facts of observation and experimental evidence in support of your statements. (J.M.B. Matric.)

8. How would you show that carbon dioxide from the air is absorbed by the living green parts of plants exposed to sunlight ? What are the changes which take place ? (Prel. Cert.)

9. How could you demonstrate the presence of starch in a green leaf ? What circumstances are necessary in order that starch may be formed in a leaf ? (O.J.)

10. How could you prove experimentally that (*a*) carbon dioxide, (*b*) chlorophyll, are necessary for photosynthesis to take place ? (C.P.)

11. Describe concisely what occurs during carbon assimilation in green plants. Explain clearly why light is necessary for carbon assimilation. (C.S.)

12. Describe experiments to show that a green plant obtains its supplies of carbon from the atmosphere.

13. Given a piece of pond-weed, say exactly how you would proceed to demonstrate the process of carbon assimilation. What conditions are essential in order that green plants may satisfactorily carry out this process ? (J.M.B. Matric.)

14. A number of green shoots of submerged water plants are cut and, while still in the water, their cut ends are introduced into the mouth of an inverted test-tube, full of water. The test-tube is suitably supported. Describe what you would expect to observe. Explain your observations, and describe how you would proceed to confirm your explanation. (J.M.B., Hr. Sch. Cert.)

15. Explain what happens when a water plant is placed in a jar of water and left for some time in bright sunlight. What differences would be observed if (*a*) a lump of ice were kept floating in the water, (*b*) the water in the jar had been boiled previously and cooled down ? (Prel. Cert.)

16. Three burettes (*a*, *b*, and *c*) are filled with water, inverted into a trough of water, and subsequently filled with air expired from the lungs. Into (*a*) is inserted a bag of germinating seeds ; into (*b*) is inserted a green leaf ; (*c*) is left. Draw the apparatus. The whole is put into a sunny window. If after three days caustic soda is added to the water in the trough, what changes would you expect to see ? Explain the results in the different burettes as fully as you can.

[Expired air contains about 4 per cent. less oxygen and 4 per cent. more carbon dioxide than the atmosphere.] (O.S.)

17. Describe any experiment that you have performed to show that a green plant in air gives out oxygen during photosynthesis.

18. Describe the changes which take place in the contents of a jar full of air, when a lighted splinter is burned in it. How would you recognise the substances produced ? In what life-process of plants do the same materials arise ?
(J.M.B., Sch. Cert. and Matric.)

19. Why is it essential for a plant to respire ? What parts of the plant are concerned in the process ? How could you show by experiment that a green plant respires ? (O.S.)

20. Write a concise account of the relation between a green leaf and the surrounding air. (C.S.)

21. What do you understand by a " food " ? What are the chief plant foods ? From what inorganic materials are these foods manufactured ? (O.S.)

22. Under what conditions will a green leaf give out carbon dioxide ? How could you demonstrate this output experimentally ? What changes are taking place in the leaf under these conditions ? (L.M.)

23. Describe one or two experiments to demonstrate that plants respire. What do you know of the nature of the process and its importance in the life of plants ? (J.M.B. Matric.)

24. Of three air-dry bean seeds which are equal in weight, No. 1 is laid aside ; No. 2 is grown in damp sawdust, in daylight, until the radicle (but not the plumule) appears ; No. 3 is grown under the same conditions, until it has well-formed leaves. All three specimens are dried at 100° C. and carefully weighed. What difference in weight would you expect to find, and why ?
If the dried specimens were now thoroughly burnt in contact with air, what differences, if any, would be found in the weight of the ash ? Give full reasons for your conclusions. (Prel. Cert.)

25. What are the characteristics of an etiolated plant ? Mention plants which are purposely etiolated during cultivation.

26. Make a careful drawing of specimen *D*, and comment on features of interest. [*D* = etiolated bean seedling.] (C.J.)

27. Describe the appearance of some flowering plant after it has been germinated and grown in the dark for some weeks.
If the plant were taken and weighed, then dried in the steam oven and the dry weight obtained, how would you expect these two weights to compare with the average weight and average dry weight respectively of the seed of the same plant. Give reasons for your conclusions. (J.M.B., Hr. Sch. Cert.)

28. How would you show experimentally the importance of light to a bean seedling about a month old ? (J.M.B., Jun. Cert.)

CHAPTER V.

LEAVES AND THE PLANT'S WATER.

10. TRANSPIRATION.

PRACTICAL.

1. The cobalt paper test.—Dip strips of filter paper into cobalt chloride solution and dry the strips. Note the blue colour. Breathe on a strip and observe that your moist breath changes the colour to pink. Fasten small pieces of freshly dried cobalt paper to the upper and lower surfaces of various leaves, with small slips of glass (or better, stripped kodak films) and paper-clips, and note which papers turn pink most quickly.

2. Water vapour given off by leaves (*a*) *of a cut shoot.*—Cover with a dry bell-jar or inverted tumbler a leafy shoot passing through a hole in a card and dipping below into water, the chinks between the stem and the card having been made up with plasticine or soft wax (Fig. 51). Expose the arrangement to bright light and notice the formation of dew on the inside of the covering tumbler. Notice that if the leaves are smeared with vaseline, no dew is deposited. What are the possible sources of the dew ?

(*b*) *Of a potted plant.*—Obtain a piece of sheet rubber, oiled silk, or lead foil, rather larger than the base of a suitable bell-jar. Cut the sheet to its centre so as to let the stem pass through, and then cement or otherwise fix it tightly to the stem and join up the cut edges. Put the bell-jar over the plant, turn up the edge of the sheet round the bell-jar and tie it in position. Expose the whole to bright light, and notice the condensation of moisture inside the bell-jar. Could any of this have been derived by evaporation from the soil ?

3. Weight of moisture given off by leaves (*a*) *of a potted plant.*—Enclose the pot and soil in sheet rubber, tying or cementing (with

rubber solution) the sheet to the stem so as to form an air-tight joint. Weigh the whole before and after exposing it to several hours' bright light. Repeat the experiment with the plant in the dark.

(*b*) *Of a cut shoot.*—Cut off the end of a twig under water in a basin (to prevent the entrance of air), and put it (still under water) into a suitable bottle of water. Cover the surface of the water in the bottle with oil (to prevent evaporation), wipe the outside dry, and weigh the whole. Expose to bright light and weigh at noted intervals of time. A spring balance (to which the bottle is hung by a wire) may be used with advantage. Record the result by a graph on squared paper. Compare the result when the plant is kept in the dark. Smear the leaves with vaseline and repeat the experiment.

(*c*) *Of different plants.*—Obtain ivy and sycamore leaves of as nearly as possible the same size. With the usual precautions put the stalk of each into a separate test-tube of water, and *then* cover the water with a layer of oil. Hang each test-tube to a delicate spring balance. Keep them side by side and record the loss in weight of each at intervals. By tracing the outline on squared paper, find the area of each leaf, and calculate the loss per square centimetre (or square inch) during the time of the experiment.

4. Farmer's potometer.—Fit a small wide-mouthed bottle with a three-holed rubber stopper (Fig. 52). Through one hole fix tightly (under water) the twig (freshly severed under water) of the shoot to be experimented on * ; fill the bottle with water and put in the stopper. Through the second hole put a tap-funnel (*F*), filled with water below the tap, and with the tap closed ; through the third hole (flush with the bottom of the stopper) put the end of a capillary tube (*T*) bent at right angles (an old thermometer tube is convenient, or a paper scale may be attached). All the joints must fit tightly.

Notice the entrance of air into the capillary tube, showing that water is being withdrawn from the bottle. It may be driven back by opening the tap for a moment, and the observation repeated. Record the time which the end of the water column takes to pass over a certain length of scale, with the apparatus (*a*) in still air, (*b*) in a draught, (*c*) in sunshine, (*d*) in a shady place,

* This may be done without injury to the twig by pushing a cork borer (rather larger than the hole) through the hole *from below*, putting the twig into the cork borer from above, and then withdrawing the borer.

(*e*) in a cool place, (*f*) in a warm place. Make a list of the conditions you find most favourable to loss of water by leaves.

Smear with vaseline the upper surfaces of the leaves of the shoot, and note any observed difference in the rate of loss. Then smear the lower surfaces as well, and repeat the test. From which side is water lost more rapidly ?

Transpiration.—Besides photosynthesis and respiration, foliage leaves perform yet a third function in the life of a plant: this is transpiration—the giving off of the plant's excess moisture in the form of vapour. That water vapour is being continually given off by ordinary leaves is easy to prove. Most detached leaves soon wither unless their stalks be put in water. A leaf weighed before and after withering is found to have lost weight. The water vapour given off by a leafy shoot may be condensed to visible drops of water by covering the shoot with a tumbler (Fig. 51) or a bell-jar (Expt. 2, p. 77). That the leaves and not the stem are chiefly concerned in the process is shown by the fact that transpiration almost entirely ceases when the leaves are removed. Moreover, a piece of dry cobalt paper * changes in colour from blue to pale pink when pressed against the surface of a leaf (Expt. 1, p. 77), showing that the leaf is really giving off moisture even though it may appear quite dry.

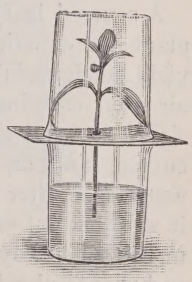


Fig. 51.—Experiment to prove that leaves, exposed to sunlight, give off water vapour.

In most cases the effect is much more marked on the lower than on the upper surface of the leaf, and may be restricted to the lower surface; many leaves, however (*e.g.* lilac), are shown by the experiment to transpire freely on both sides. In short, transpiration is most active from leaf-surfaces on which (as Expt. 1, *a*, p. 50, shows) the tiny pores called stomata are most abundant, and takes place but slowly through parts of the skin where stomata are absent. The conclusion that the **water vapour chiefly escapes from the leaf through the stomata** is borne out by the fact that transpiration is practically stopped

* Filter paper soaked in cobalt chloride solution and then dried.

if the stomata are blocked up by vaseline or castor oil, or in the dark, when they are closed (p. 104). If the leaf skin is very thin, however, a certain amount of transpiration takes place even when the stomata are closed.

Rate of transpiration.—The actual amount of water transpired by a potted plant in a given time may be found by covering up the pot and contained soil with some waterproof material as in Expt. 3, *a*, p. 77, leaving only the stem and leaves exposed to the air, and weighing the whole at intervals. The results obtained apply, of course, only to the particular plant and the conditions prevailing at the time.

A severed leafy shoot is often more convenient than a whole plant for experiments in transpiration, and may be made to yield much useful information, if precautions be taken to prevent air from entering at the cut surface. To avoid this, it is best either to bend the twig or stem under water in a basin when cutting it off, or, if this is impracticable, to cut off the end under water soon after removing the shoot from the plant, and to keep it with the cut end in water. A fresh surface should be exposed in the same way, just before the experiment. If possible the end should also be kept covered with water whilst the shoot is being fixed into the vessel to be used. The specimen should be given time to become accustomed to the temperature and the new conditions generally, before any measurements of the weight or volume of water lost are made.

Transpiration rates of different plants.—Shoots or leaves of various plants, dipping in water in this manner, may be kept for a time under similar conditions, and a comparison made of the rates at which their leaves lose water vapour. For this purpose it is convenient to have the specimens in small bottles or test tubes suspended by wires to delicate spring balances, the water being covered (*after* insertion of the shoots) with a layer of oil to prevent evaporation from its surface. The loss of weight (which is then plainly due to transpiration only) is read off in each case at regular intervals. After the experiment, the leaf area of each specimen is measured by tracing the outline of the leaves on squared paper, and the loss per hour per unit of leaf area of each is thus obtained. By

experiments such as these it is possible to show that even under similar conditions of temperature, lighting, etc., the leaves of some plants transpire much more slowly than those of others. Leaves of evergreen and deciduous trees give strikingly different results.

Conditions affecting transpiration.—For comparing the effect which variation of lighting, temperature, air-currents and other conditions have upon the rate of transpiration of the *same* shoot, **Farmer's potometer** (Fig. 52) is convenient. This is a simple arrangement for measuring the rate at which a transpiring shoot withdraws water from a small full bottle. For this purpose the bottle is fitted with a fine (capillary) tube *T*, containing water continuous with the water in the bottle. As the water in the bottle is absorbed by the transpiring shoot, the water in the capillary moves along to take its place. The movement of the end of the fine column of water may be rendered more obvious and its rate measured by means of an attached scale.

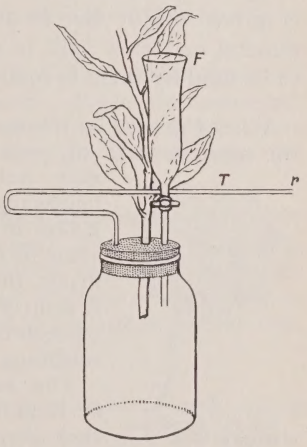


FIG. 52.—Simple Potometer. (After Farmer.)

Since the amount of water which the shoot is withdrawing from the bottle may be assumed to be equal to the amount being transpired, we may measure the comparative rates of transpiration by noting the speed at which the end of the water column moves along the scale when the apparatus is placed under different conditions. Transpiration is found to increase with the intensity of the light, and (as might be expected) in circumstances which increase the rate of evaporation of water, viz. higher temperature, lower relative humidity, freer circulation of air, etc.

The actual, as well as the comparative, rate of transpiration may also be measured by Farmer's potometer if the capillary tube has been calibrated, so that the fraction of a cubic centimetre represented by one division of the scale is known.

Why transpiration is necessary.—It might be supposed that the need for getting rid of excess water could be avoided by taking in less water. What the roots absorb from the soil, however, is not water only, but various dissolved mineral salts (Chap. V.) necessary for the manufacture of certain foods. Soil water is so dilute a solution of these salts that the plant is compelled to take in much more water than it needs, in order to get as much of the salts as it requires. The excess water is given off in the form of vapour by transpiration; the mineral matter it held in solution is left behind in the leaves, to be used by them in food-making (p. 115).

When the need for mineral matter is specially urgent (as during the rapid growth of certain seedlings), ordinary transpiration may not be able to keep pace with the necessary rate of intake of the soil-water, and leaves in such circumstances may get rid of some of the excess water in the form of liquid drops, through special pores called **hydathodes**. A drop of water, formed in this way, is often to be seen on the tips of the first leaves of wheat seedlings.

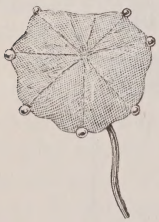


FIG. 53.—Exudation of drops of water from a leaf of *Tropaeolum*. (After Strasburger.)

The same difficulty arises whenever the surrounding air is so saturated with moisture that evaporation (and therefore transpiration, p. 81) is interfered with. It is, therefore, not surprising to find that hydathodes are common in plants growing in marshes (p. 294), and that drops of water are exuded from the leaves of Tropaeolum and other garden plants after a warm moist night. Hydathodes occur, as might have been expected, at the ends of veins, and therefore (p. 53) at the tips of the teeth of serrate leaves possessing them (*e.g.* lady's mantle).

Since transpiration is essentially a process of evaporation, during which heat is always absorbed, it serves a further useful purpose in preventing leaves from becoming too hot during intense sunshine.

11. SAFEGUARDS AGAINST EXCESSIVE TRANSPIRATION.

PRACTICAL.

1. Effect of cuticle illustrated.—Wet three similar sheets of blotting or filter paper with the same number of drops of water from a pipette. Cover one sheet with a single layer of thin waxed paper (as used for packing biscuits, etc.), and the second sheet with two or three layers; leave the third sheet uncovered. Expose them side by side to the air and compare their rates of drying.

2. Effect of stagnant air.—In each of two similar porcelain dishes put 10 drops of water from a pipette. Leave one uncovered, and lay a thin sheet of cotton-wool loosely over the other. Leave them side by side until the first is dry, and then examine the other.

3. Effect of reduction of leaf surface illustrated.—Take two similar sheets of blotting or filter paper. Fold one repeatedly to form a narrow "spill," and pin the folds together. Wet each sheet thoroughly with the same number of drops of water from a pipette, then hang them up side by side and notice which dries first. Explain.

Xerophytes.—So long as an abundance of water is forthcoming from the soil to replace the loss from the leaves, free transpiration has no ill effects: indeed, it is an advantage to the plant. It becomes highly dangerous if for any reason the roots are unable to supply enough water to keep pace with it. The condition of drought, or water starvation, may arise in very different circumstances, but evidently it can be borne only by such plants as are able to restrict their transpiration to correspond with their powers of water absorption, and at the same time leave the margin necessary for food-making; for, naturally, *any condition which stops transpiration brings food-manufacture also to a standstill.*

Actual drought, that is, real scarcity of water, is the condition obtaining in very sandy or thin soils, or during a prolonged dry season. *Physiological drought* occurs when water is present, but cannot easily be taken up by the roots. Such water may be unavailable because (*a*) it is held too tenaciously by the soil

(p. 111); (*b*) it contains too much salt in solution (p. 273); (*c*) it is too "sour" (p. 279); (*d*) the roots are too much chilled to carry out their activities.

Drought-bearing plants, or **xerophytes** (as they are called), may therefore be expected to show in their leaves some peculiarity which restricts transpiration, and in many cases to show also signs of being badly nourished.

Xerophytic modifications.—(1) In nearly all cases, as a leaf grows to its full size, the outside layer of its skin changes into a more or less waterproof sheet called **cuticle**. When the cuticle is

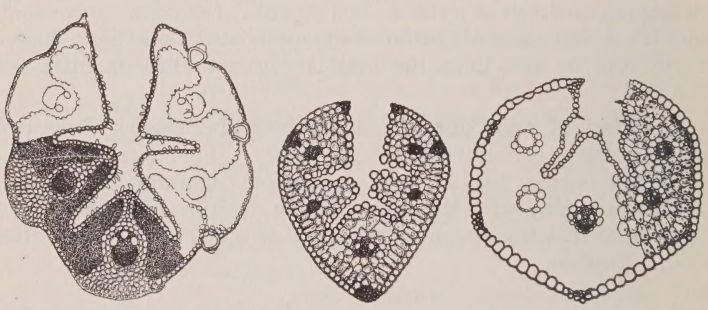


FIG. 54.—Transverse sections of the leaves of three typical grasses of heath and moorland. *A*. Matgrass; *B*. Sheep's Fescue; *C*. Wavy Hairgrass. The upper surface, which bears the stomata, is permanently infolded. Much magnified. (After Miall.)

thick, the skin is leathery, and transpiration is entirely restricted to the stomata. A deposit of *wax* in the cuticle (*e.g.* holly) may make it still more impenetrable. (2) A very common hindrance to transpiration is some means of protecting the surface of the leaf, and especially the stomata, from draughts. The **stagnant air** close to the stomata then remains more or less saturated with moisture, and evaporation is therefore slow. Examples of this principle are found in (*a*) very hairy leaves (silverweed, mullein, coltsfoot, some thistles, etc.), (*b*) the rosette habit (p. 199), (*c*) sunken stomata (pine, etc.), (*d*) folded or grooved leaves (marram, sheep's fescue, and certain other grasses (Figs. 54 and 169), crowberry, heather (Fig. 275), etc.). (3) **Reduction of the leaf surface**, so marked in the needle-shaped leaves of the pines (Fig. 345), firs, gorse, etc., obviously restricts transpiration. The ordinary work of leaves is largely carried out by the green,

ridged stem in the case of gorse (p. 275) and in such " switch plants " as broom ; it is wholly carried out by the stem in cacti, asparagus (Fig. 55), butcher's broom (Fig. 56), horsetail, etc. In these plants the foliage leaves are either reduced to spines, or small scales, or are absent altogether, and branches of the

FIG. 55.—Shoot of Asparagus bearing narrow leaf-like branches (cladodes) and four berries. (After Figuier.)

FIG. 56.—Butcher's Broom. *f*, leaf ; *cl*, cladode ; *bl*, flower. (× 1.) (After Strasburger.)

stem become more or less leaf-like and are called *clàdodes*. (4) The thick **succulent leaves** or stems of various plants growing on the seashore (p. 273), and of such rock-plants as houseleek and stonecrop, absorb and store rain water and dew.

Seasonal xerophytes.—During winter, when the soil is very cold, the chilled roots of plants become so " numbed " that they are unable to absorb water, even though the ground may be quite damp. Any plant which in such circumstances continued to transpire freely would plainly be in danger, and British plants are therefore compelled to be xerophytes in the winter, even though they may grow in situations furnishing an ample supply of water at other seasons. **Trees and shrubs** the leaves of which transpire very slowly are able safely to retain

their leaves even in winter, and such plants are *evergreen*. Familiar examples are the pines (p. 459), firs, holm oak (p. 443), holly, ivy, heathers (Fig. 172), etc. On the other hand, trees and shrubs which have thin, broad leaves not specially protected by thick cuticle, are *deciduous*, that is, shed their leaves before winter and thus escape the danger, since transpiration from the stem is prevented by the corky bark. Examples are oak, beech, ash, sycamore (p. 174), elm, bilberry, etc.

Herbaceous plants transpire from the stems as well as from the leaves. This fact explains why in most of our herbaceous *perennials* all the parts above ground die before winter. The plants survive by means of underground rhizomes, corms, tubers, bulbs, swollen roots, etc., from which new aerial shoots arise in the following spring (Chap. XII.). The rosette habit of *biennials* in winter (p. 206) also limits transpiration. Among *annuals*, only the seeds (which are xerophytic structures) survive the winter.

EXERCISES V.

1. Give an account of the activities of an ordinary green leaf (*a*) during the day, and (*b*) during the night. Describe one experiment supporting your statements. (L.M.)

2. Two large leaves, *X* and *Y*, are picked from the same tree at the same time; the whole upper surface of *X* is smeared with vaseline, the lower surface of *Y* being treated similarly. They are then found to weigh : *X* 5·0 grams, *Y* 5·2 grams.

They are left in dry air for two days under identical conditions and then weighed again. The weights are now : *X* 3·2 grams, *Y* 5·0 grams.

Discuss the significance of these experimental results.

(J.M.B. Hr. Sch. Cert.)

3. Describe any two experiments you have performed to show that water vapour is given off from the leaves of plants. What part do the stomata take in the process ?

(J.M.B. Sch. Cert. and Matric.)

4. How would you show :

(*a*) that transpiration takes place in a plant ;

(*b*) from what parts of the plant it takes place ;

(*c*) that it is under the control of a living plant ?

(J.M.B. Sch. Cert. and Matric.)

5. How would you measure the rate at which water is given off by the aerial organs of a green plant ? How would the rate be

affected by placing the plant (*a*) in a cold room, (*b*) in a draught, (*c*) in sunlight, (*d*) in the dark ? (O.S.)

6. Describe experiments by which you would measure the giving off of water vapour by a plant. Indicate how the amount varies in relation to different external conditions. (J.M.B. Hr. Sch. Cert.)

7. By what features of form and structure may plants be protected from injury through excessive loss of water ? (C.J.)

8. Give an account of the part played by the leaf in the transpiration of water vapour from the plant. Describe two leaves : (1) one that is modified to *hinder* transpiration, and (2) one that is modified to *encourage* transpiration. (J.M.B. Jun. Cert.)

9. How do you account for the following facts, (*a*) that plants in a garden often wilt or hang limp on a hot dry day, (*b*) that liquid water is exuded by the leaves of plants such as Nasturtium (*Tropaeolum*) in the early morning ? (J.M.B. Matric.)

10. Give an account of the stem and leaves of some xerophytic plant with which you are familiar. Give the name of the plant. (C.J.)

11. With the coming on of winter many plants undergo considerable changes of appearance. Give a general account of the various structures and modifications which different plants possess which enable them to live through this difficult time without injury. (N.F.U.)

12. Why do most trees in Britain shed their leaves in autumn ? What effect has this process on transpiration, and how are the characters of the leaves of most of our evergreens connected with transpiration ? (J.M.B. Sch. Cert. and Matric.)

13. What differences have you observed between the leaves of evergreen and deciduous trees ? How do these differences affect the physiological processes and the resistance to adverse conditions of the two kinds of trees (*a*) in summer, (*b*) in winter ? (J.M.B. Hr. Sch. Cert.)

CHAPTER VI.

THE CELLULAR STRUCTURE OF LEAVES.

* 12. PRELIMINARY MICROSCOPE WORK ON CELLS.

PRACTICAL.

1. A unicellular green plant.—(*a*) Scrape off a very small particle of the green powdery crust which forms on damp walls, tree trunks, etc., and put it in a small drop of water on a microscope slide. Cover with a cover-slip, avoiding the inclusion of air bubbles, and rub the cover carefully about until the green particle is quite broken up. Wipe off any water outside the cover, and examine the preparation with, first, the low and then the high power of the microscope. Notice the rounded green cells, some forming pairs, or groups of four or more. Each cell is an individual plant called *Protococcus*. With the high power distinguish in each (1) the colourless *cell-wall*, enclosing (2) a green plate called the *chloroplast*, and (3) a colourless jelly, the *protoplasm*.

(*b*) Place a drop of weak iodine solution at the edge of the cover-slip, and draw it under by holding a shred of blotting paper against the opposite edge of the slip. The iodine kills the cells, but stains the protoplasm and cell wall brown or yellow. Look for a more deeply stained rounded particle (the *nucleus*) in the protoplasm, and for blue-stained starch grains in the chloroplast.

2. Other simple cells. (*a*) *Fruit pulp*.—Examine in the same way a small speck of the " floury " pulp of the ripe fruit of apple, tomato, privet, etc., and make out the cell wall, the granular protoplasm, and *vacuoles* or drops of liquid (cell sap) which may be coloured. Treat the cells with weak iodine solution and note any changes in colour.

(*b*) *Root hairs*.—Germinate seeds of mustard or cress on muslin over water until the young roots show root hairs. Remove a

* This section may be omitted on a first reading.

short piece of the root, bearing hairs (as near the tip as possible), put it in a drop of water on a slide and cover as before. Examine with the high power, and notice that each hair is a single elongated cell. Stain with weak iodine solution and draw a few of the shorter hairs, showing cell wall, protoplasmic lining with nucleus, and large vacuole.

3. Plasmolysis.—Treat fresh cells of *Protococcus*, fruit pulp, and root hairs with a 10 per cent. solution of common salt, and notice that the protoplasm shrinks away from the cell wall. (This shrinkage is especially well seen in cells with coloured cell-sap, *e.g.* the blue hairs on the stamens of *Tradescantia* flowers.) A cell in this condition is said to be *plasmolysed*. Using a shred of blotting paper, as in 1, *b*, replace the salt solution by water, and observe that the cell resumes its former condition.

4. Osmotic pressure in a cell model.—Obtain a pig's bladder, half fill it with treacle or syrup, tie up the neck without including air, and hang up the bladder so that its lower end dips into water Keep the bladder moist. Notice that the quantity of liquid in the bladder increases until it becomes full and tightly stretched, showing that it has absorbed water through its wall. Next allow the distended bladder to remain dipping into strong syrup or brine, and notice that it becomes flabby again. Compare the plasmolysis of a cell in Expt. 3 above. (*N.B.*—The cell wall is *not* represented in the model, but only the cell contents.)

5. Modified cells separated by maceration.—(*a*) Pick out a few of the more "stringy" portions of stewed rhubarb, mount a very small quantity in water, and examine with low and high powers.

(*b*) Cut a little of any herbaceous stem into small pieces and soak them for a day in a mixture of three parts of alcohol and one of hydrochloric acid. Take out, wash with water and weak ammonia, and tease a very small piece with needles on a microscope slide. Mount in water and examine.

(*c*) Split a short length of any woody twig (*e.g.* willow) into small pieces. Cover them with strong nitric acid in a test tube, add one or two crystals of potassium nitrate and warm in a fume chamber. When the action has ceased, rinse the material repeatedly with water until the acid has been removed. Then tease a little with needles in water, mount in water or glycerine and examine with the microscope.

Draw as many different types and shapes of cells as you can find.

Cells in general.—By means of the microscope it is possible to examine many details of the machinery by which the plant carries out its various activities. Such observations as are described on pp. 89 and 90 show that a stem—for example—is a somewhat complicated structure, composed (as is the rest of the plant) of very small blocks (called *cells*) of various shapes and sizes (Figs. 59, 62 and 67); much as a complicated building may be composed of bricks and stones, etc., of various shapes and sizes according to the positions they occupy and the purposes they serve. The cell, more or less modified, may thus be regarded as the unit of plant structure. Before we go on to study the detailed architecture of any of the parts of a plant, as revealed when moderately magnified by means of a microscope, it will be well to learn something of the nature of the building materials—the cells—themselves.

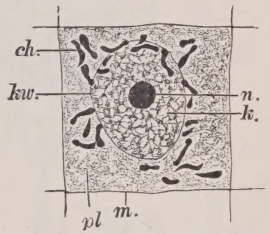


FIG. 57.—A single cell from the root tip of the Oak. *k*, nucleus; *kw*, nuclear membrane; *n*, nucleolus; *pl*, protoplasm; *ch*, plastids; *m*, cell wall. (× 1000.) (After Lewitzky.)

A cell (Fig. 57) is essentially a tiny block of living jelly or slime called **protoplasm**, containing in its interior a special rounded portion called the **nucleus**, and (in plants) usually surrounded by a film of cellulose (p. 19), which constitutes the **cell wall**. The nucleus controls the activities of the rest of the protoplasm of the cell. Besides the nucleus, certain solid particles called **plastids** are embedded in the protoplasm.

Plastids, in the cells of such parts of plants as are exposed to light, usually become coloured green by the formation of the colouring matter called chlorophyll in them; they are then called *chloroplastids* or chloroplasts. The plastids of cells near the surfaces of flower petals (and often sepals), as well as of ripe fruits, often develop colours (*e.g.* red and yellow) other than green; such plastids are called *chromoplastids*. Most cells, however, are too far from the surface of the plant to be affected by light, and their plastids remain white (*leukoplastids*).

Division of cells.—In parts of the plant which are growing in size (*e.g.* at the tip region of stems and roots and of their

branches, and in the cambium layer—just outside the wood —which in many plants causes the thickening of stems and roots), the cells remain in the comparatively simple condition just described, until at an early stage each divides into two. In this process of cell division (Fig. 58) the nucleus undergoes certain changes by which it is accurately halved, and the plastids also divide. Indeed, every nucleus has been formed

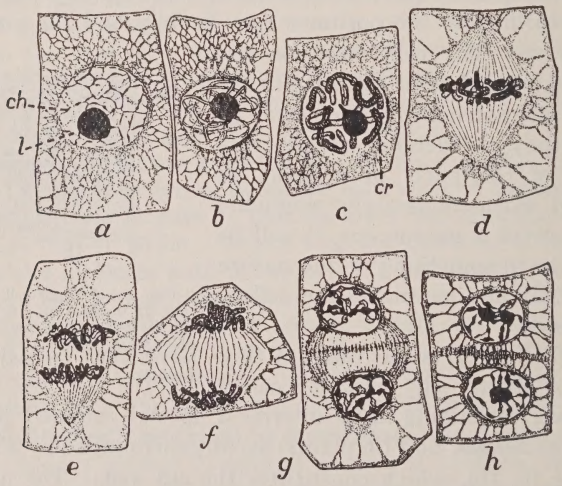


FIG. 58.—Stages of nuclear and cell division in the root of Maize. *a*, first stage (mother cell); *h*, final stage (two daughter cells). (After Curtis.)

from a pre-existing nucleus, and every plastid from a pre-existing plastid. One half-nucleus, with a portion of the general protoplasm and certain of the plastids, is then marked off from the other half-nucleus and its associated protoplasm and plastids, by the formation of a film of cellulose (*i.e.* a cell wall) between them. The original "mother cell" (*a*, Fig. 58) has thus become two "daughter cells" (*h*), each of which may perhaps repeat the process after growing a little larger.

It is, however, only in certain regions, such as those mentioned above, that the cells have this habit of indefinitely repeated division. In the greater part of the plant the cells soon cease to divide, but undergo changes in size, shape and

other respects which fit them for the performance of definite functions. A group of cells of the same kind, and doing similar work, is called a **tissue.**

The nutrition of the cell.—During its development from the simple condition described above to its final form, the cell is dependent on solutions of *food*, which soak freely through the cell wall. The food is used by the protoplasm, partly as a source of energy, and partly as material for growth in size of the cell as a whole; it also furnishes material for the thickening of the cellulose wall which usually goes on, as well as for the formation of various reserve foods (p. 17) and other substances which accumulate in the cell. Drops of liquid called *cell sap* also make their appearance within the cell at an early stage, and usually run together to form a central **vacuole**, so that in a mature cell the protoplasm with its nucleus forms a somewhat thin layer lining the cell wall (Fig. 59, *B*).

Osmotic pressure.—The outside film of the layer of protoplasm which lines the permeable cell wall itself is known as the *ectoplasm*. It has a remarkable property which is of great importance in the life of the cell, and therefore of the plant as a whole; for while it freely allows *water* to pass through it into the cell from a weaker solution outside, or to pass out of the cell to a stronger solution outside, it differs from the cell wall in obstructing to a varying extent the passage of

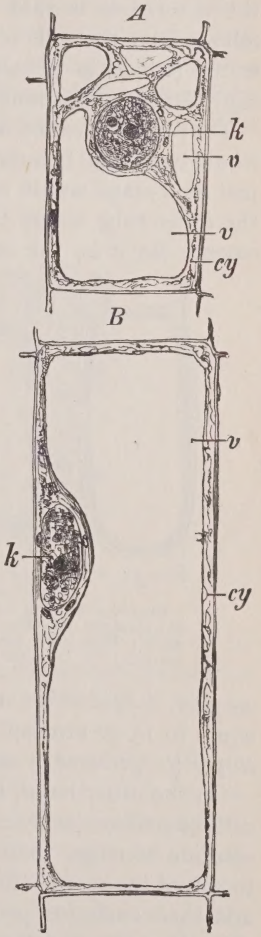


FIG. 59.—Two cells taken at different distances from the growing point of shoot of a flowering plant; *k*, nucleus; *cy*, protoplasm; *v*, vacuoles, represented in *B* by the sap cavity. (Somewhat diagrammatic. × *circa* 500. After Strasburger.)

substances dissolved in the cell sap. Being thus permeable to water, but impermeable to certain substances dissolved in water, the ectoplasm is said to form **a semi-permeable membrane.** It follows that the cells of a plant having access to plenty of soil water (which is a very weak solution as compared with cell sap) take in water much more freely than they give it out.

The pressure, called **osmotic pressure**, thus set up inside the cells would be enough to burst them but for the support of the cell walls, just as a stage would come in pumping up a bicycle tyre when the inner tube would burst, were it not supported by the tyre cover. As it is, the cell becomes so tightly distended—or, as

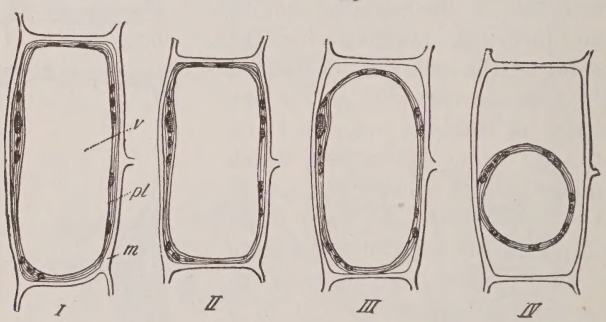


FIG. 60.—A young cell from the cortical parenchyma of the flower-stalk of *Cephalaria leucantha*. *m*, cell wall; *pl*, protoplasm; *v*, vacuole. I, In water; II, in 4 per cent. potassium nitrate solution; III, in 6 per cent. solution; IV, in 10 per cent. solution. (After De Vries.)

we say, *turgid*—that the osmotic pressure of its sap may be equal to 15-20 atmospheres. Tissues in such a healthy state of *turgor* (*turgescence* or *turgidity*) are tense and stiff.

On the other hand, if water be steadily withdrawn from any cells of a tissue (as by evaporation, or by contact with an outside solution stronger than the cell sap), water will drain from cell to cell of the rest of the tissue to the point of loss; the vacuoles and their enclosing protoplasm will shrink to the middle of the cells (Fig. 60), and the whole tissue will become flabby or limp, unless other water be available to supply the loss. Cells in this condition are said to be **plasmolysed.** Thus the leaves of a plant may droop on a hot day because their cells are losing water by transpiration more quickly than they are receiving

fresh supplies from the soil; a lettuce, a piece of raw potato or a stick of celery, put into salt solution, will become soft, but will regain its crispness if replaced in fresh water (Fig. 61); plums or other fruit standing in strong sugar solution before being boiled for jam become soft and wrinkled, but swell again, as a prune swells, if soaked in water. The passage of watery solutions through a semi-permeable membrane in the manner described above is called **osmosis.**

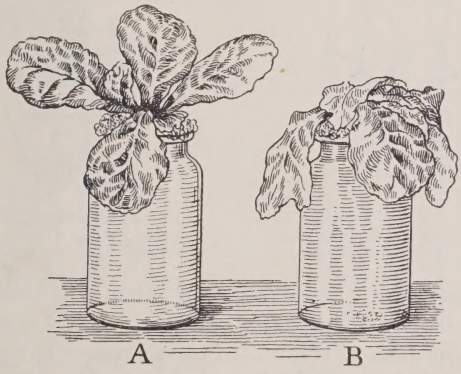


FIG. 61.—Lettuce plants in solutions. *A*, in tap water; *B*, in a 3 per cent. solution of common salt. (After Duggar.)

The ageing cell.—During the cell's life, the cellulose of its wall may be more or less altered into a waterproof substance called cutin (seen well in the cuticle of the epidermis of leaves), or even into wood, cork, or gum.

All the changes in size, shape and composition of the cell wall and its contents are brought about by the activity of the protoplasm—the only part of the cell which is alive. Finally the protoplasm dies, and the active career of the cell is at an end. Its contents dry up, and nothing is left of it but an empty box, the cell wall, which may nevertheless be very useful to the plant for mechanical support, or may serve with its neighbours as a channel for the passage of liquids.

Shapes of cells.—In their early stages, cells are roughly similar to one another in appearance, and fit closely together; but in many cases a cell grows more quickly in some parts than in

others, and therefore changes greatly in shape as well as size as it becomes older. Root hairs are an example, and many of the epidermal cells of certain leaves and stems also grow out to form hairs which may assume very strange shapes (Figs. 62 and 63).

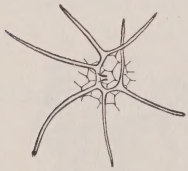


FIG. 62.—Unicellular hair from lower epidermis of Stock leaf. (× 45.) (After Strasburger.)

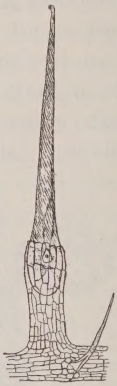


FIG. 63.—Multicellular hair of Stinging Nettle. (× 30.) (After Strasburger.)

When a cell is not markedly longer than it is broad or thick, it is said to be *parenchymatous* in shape, and a tissue composed of parenchymatous cells is called **parenchyma**. The greater part of the plant often consists of parenchyma (Figs. 68, 82 and 93). On the other hand, a cell which is very long in proportion to its width or thickness is said to be *prosenchymatous* in shape; a tissue composed of such cells is called **prosenchyma**.

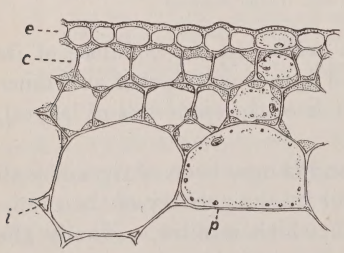


FIG. 64.—Epidermis (*e*), collenchyma (*c*), and thin-walled parenchyma (*p*) in Balsam. *i*, intercellular space. (× 150.) (Strasburger.)

Strengthening tissue.—When the cell wall is so much thickened or changed in composition (*e.g.* from cellulose to wood) that it becomes hard, the cell is described as *sclerenchymatous*,* whatever its shape may be. **Sclerenchyma**—that is, a tissue composed of such hard cells—naturally confers increased mechanical strength on the parts where it occurs. Another kind of supporting

* Greek *skleros*, hard.

or stiffening tissue is called **collenchyma**; this consists of parenchyma cells the cellulose walls of which are specially thickened at their corners, where the cells abut on their neighbours (Fig. 64). An important difference between collenchyma and sclerenchyma is that the former tissue is elastic and can stretch considerably without tearing, while the latter is much more rigid. Collenchyma is, therefore, specially useful

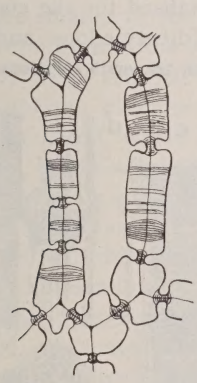


FIG. 65.—A single cell of the endosperm of *Ladoicea*, showing discontinuous thickening of cellulose wall. (× 270.) (After Gardiner.)

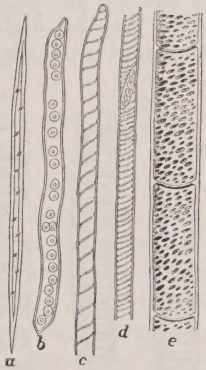


FIG. 66.—Thickened cell-walls. *a*, *b*, *e*, pitted; *c*, *d*, spiral. (After Strasburger.)

in regions which are still growing in length, while sclerenchyma is almost restricted to parts of the plant which have finished elongating.

Thickening of cell walls.—The new cellulose which is laid down on the inner side of the cell wall is not usually deposited evenly; on the contrary, certain parts of the wall are left thin (Figs. 65, 66 and 67). When these thin places are small they are called pits, and the wall is said to be **pitted**. Often (especially in regions which are still elongating) the thickening material is laid down in **spiral** bands or in rings (**annular** * thickening) on the cell wall, and such walls can stretch a little without tearing. In parts which have finished growth in length, the thickening may form parallel ledges, or a network, on the cell wall, the type of thickening being described as **scalariform**,† or

* Lat. *annulus*, a ring

† Lat. *scala*, a ladder.

reticulate * respectively. Such discontinuous thickening is an obvious advantage, not only because it often safely allows a certain amount of bending or stretching of the part, but also because liquids are able to pass more freely in and out of the cell through the thin places in the wall.

Conducting tissues.—In the veins of the leaves, and in the vascular bundles which are their continuations in the stem and roots, certain cells early become specialised for the conduction of liquids. In the highest plants (dicotyledons and monocotyledons) it is usual for the **cells which transmit solutions from the**

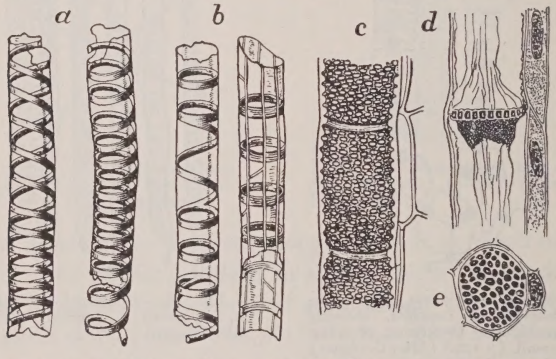


FIG. 67.—Conducting cells of vascular bundles. *a*, *b*, *c*, spiral, annular and reticulate vessels of the wood. (× 150.) *d*, *e*, longitudinal and cross-sections of sieve tube and companion cell. (Highly magnified.)

soil to the leaves to be arranged end to end and to grow very long in proportion to their width. The walls of certain of these cells, formed whilst the particular part of the plant is still growing in length, are thickened in the spiral or annular manner; while those of corresponding neighbouring cells formed later, when the part has ceased to elongate, are thickened in the pitted or reticulate manner (Fig. 67). The cellulose of their cell walls is *lignified*, *i.e.* so altered that it becomes wood; and finally, just before the protoplasm of each cell dies, the end-walls break down so that cells of the same row form a continuous wooden tube known as a **wood vessel**. The woody region of the vascular bundle, in which these changes take place, is called the **xylem.**

* Lat. *reticulum*, a network.

Among the **cells which distribute leaf-made food** to the rest of the plant the most characteristic are the **sieve tubes.*** Certain cells of the young vascular bundles of monocotyledons and dicotyledons become very long and arranged end to end somewhat as the future wood vessels do; but their walls, instead of being lignified, remain thin and of cellulose. Presently, by the formation of a wall, each cell divides into two cells lying side by side —one, the smaller of the two, containing the nucleus and part of the protoplasm of the original cell; this is called a *companion cell.* The larger cell, left without nucleus, but with the bulk of the protoplasm, becomes a sieve tube. It receives this name because each end, where it abuts on another sieve tube of the same row, becomes perforated, like a sieve, with small holes; the perforated areas are called *sieve plates* (Fig. 67, *e*). The sieve-tube region of a vascular bundle is called the **phloem** or **bast.** The sieve tubes with their companion cells give the phloem a characteristic "diamond window-pane" appearance in transverse section when seen through the microscope. This is well shown in Fig. 96. In longitudinal section the sieve plates—especially if artificially stained—make the sieve tubes easily recognisable.

Cavities, channels and canals formed by the **separation of cells** also occur in many plants. These may either contain air (Figs. 68 and 186), or act as receptacles or ducts for resin (*e.g.* pine), oils (*e.g.* Umbelliferae), etc. In other cases, vessels containing a milky juice called *latex* (which stiffens or "sets" on exposure to air) are formed by the branching of cells (*e.g.* spurges) or the breaking down of cell-partitions (*e.g.* poppy, harebell, dandelion (p. 404)).

13. THE MICROSCOPIC STRUCTURE OF LEAVES.

PRACTICAL.

1. The epidermis.—Tear across various leaves (tulip and elder answer well, but several other kinds should be tried) and strip off small pieces of skin (epidermis) from both upper and lower surfaces. Place them in turn on a microscope slide with a drop of water, and cover with a cover-slip, avoiding inclusion of air.

* See p. 158.

(Any film of air adhering to the surface may be removed by adding a drop of alcohol.) Examine with first the low and then the high power of the microscope. Notice the wavy outlines of the colourless *cells*, of which the epidermis is chiefly composed. In some strips notice pairs of sausage-shaped green cells (*guard cells*), each pair enclosing an opening or intercellular space (*stoma*). Note in each leaf whether stomata occur in the upper or the lower epidermis, or in both. Examine the guard cells with the high power, focussing carefully, and study the green grains (*chloroplasts*) to which each owes its colour. Draw one or more pairs of guard cells with the neighbouring colourless epidermal cells, as seen under the high power.

Examine strips of epidermis torn from various hairy leaves, *e.g.* wallflower, lavender, silverweed, etc., and from young shoots of ivy, and notice that each hair is formed by the outgrowth of one or more cells of the epidermis. Draw various types.

2. Transverse section of a leaf.—Roll up tightly a leaf of sunflower, ivy, laurel, beech, tropaeolum, etc., and cut thin slices (sections) across the roll with a sharp wet razor. Or hold portions of leaf between two pieces of pith * or carrot, and cut through the whole. Put the sections in a small saucer (*e.g.* watch glass) of water, lift out the thinnest with a fine brush, place them in a drop of water on a slide, cover, and examine. Note (*a*) *the upper epidermis*, showing as a single layer of squarish colourless cells fitting closely together (some perhaps growing out to form *hairs*) ; their outer walls form a continuous shining membrane called the *cuticle* ; (*b*) *the lower epidermis*, usually differing from (*a*) only in being interrupted here and there by *stomata*, each stoma forming a gap between two green *guard cells* and opening into an air space in the interior of the leaf ; (*c*) *the mesophyll*, consisting of the green cells packed between (*a*) and (*b*). Distinguish between the somewhat closely arranged *palisade cells* of the upper part of the mesophyll, and the more loosely packed and irregular cells of the *spongy* tissue of the lower part, with its larger *intercellular spaces* ; study the green grains (*chloroplasts*), which give the mesophyll cells their colour ; (*d*) *the vascular bundles* (veins), circular, elliptical or elongated in outline according as the section has cut them transversely, obliquely or lengthwise. The bundles usually run through the lower part of the mesophyll. Observe the difference in appearance of the upper, or *wood*, region and the lower, or *bast*, region of each bundle.

* To be obtained from dealers.

Make a careful drawing of a short section from upper to lower epidermis as seen with the high power of the microscope, showing all points mentioned above, and fill in details from the thinnest portions of the sections.

The minute structure of leaves.—The student who has made himself familiar with the commonest modifications of cells as described on pp. 91 to 99 will find the minute structure of leaves full of examples of perfect adaptation of cell form and arrangement to function. A typical leaf is made up (as a transverse section (Fig. 68) shows) of three well-marked regions :

(1) the mesophyll,
(2) the vascular bundles,
(3) the epidermis.

The mesophyll.*—This is the all-important part of the leaf, since it has the outstanding function of making the plant's food. The mesophyll consists of an enormous number of cells, each containing chloroplasts or chlorophyll grains, and therefore capable (if supplied with carbon dioxide, water and light under suitable conditions of temperature, etc.) of making food (p. 72). The cells are so arranged among themselves as to secure the best conditions of lighting. In the first place, the leaf is thin, for passage through three or four layers of such cells is sufficient to deprive ordinary daylight of most of the energy available for photosynthesis. Secondly, the upper cells of the mesophyll (which intercept most of the light, and therefore carry out most of the photosynthesis) are usually arranged with their lengths at right angles to the surface of the leaf. They are packed somewhat closely, but with numerous communicating chinks containing air between them. Since in transverse sections of most leaves they somewhat resemble one or two rows of palings, the cells of this upper part of the mesophyll are called the **palisade cells.** The remaining mesophyll cells are more irregular in shape and more loosely arranged, with more extensive communicating intercellular spaces filled with air ; they constitute what is called the **spongy mesophyll** for this reason. They receive and utilise the diffused light which reaches the leaf

* Greek, *mesos*, middle, and *phullon*, a leaf.

from below, as well as any which may have filtered through the palisade cells from above.

The vascular bundles, cut through in various directions according to the angles at which they meet the plane of section, are

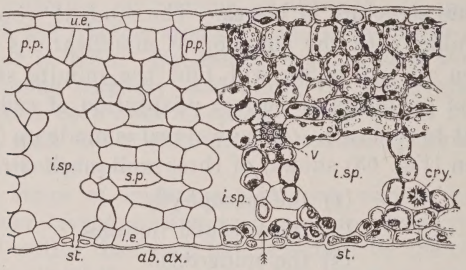


FIG. 68.—Transverse section of leaf-blade of Privet. The cell-contents are omitted on the left side. *ab.ax.*, the abaxial or lower surface; *u.e.*, upper epidermis; *l.e.*, lower epidermis; *i.sp.*, intercellular space; *v.*, vascular strand; *st.*, stoma; *p.p.*, palisade parenchyma; *s.p.*, spongy parenchyma; *cry.*, crystal. (× 50.) (After Bower.)

visible in the section (Fig. 68, *v*) among the lower (spongy) mesophyll, with the neighbouring cells of which they are in close contact (Fig. 69). This latter fact is significant, for the mesophyll cells (*a*) receive their necessary soil-water from the bundle, while they (*b*) pass on the food they have made to the bundle, for distribution to the rest of the plant. Indeed, it is not difficult to recognise—especially in cross sections of the principal bundle (the midrib) and other large veins—the cut ends of the wood vessels (which transmit soil-water) in the upper part, and the sieve tubes and companion cells of the lower part of the bundle. Surrounding each bundle is a cylindrical "bundle-sheath" made up of a layer of cells with thick walls.

FIG. 69.—Termination of a vascular bundle in a leaf of Balsam. (× 120.) (After Schenck.)

Conflicting needs of the mesophyll.—The wet mesophyll cells, on the healthy condition and activity of which the welfare of the plant so obviously depends, would lose water with fatal rapidity by evaporation if they were not more or less shut off from the surrounding air. Yet it would be equally fatal

for them to be deprived completely of air, since the carbon dioxide which they need for photosynthesis is derived from the air. Further, a certain amount of evaporation (transpiration) is necessary to ensure the continued flow of soil-water, with its dissolved salts, from the roots, through the wood vessels of the vascular bundles, to the mesophyll cells of the leaves. How these various needs, more or less conflicting as they are, are met is to be understood by microscopic examination of the epidermis of the leaf.

The epidermis.—The epidermis or skin of the leaf is a single layer of flat cells, generally of wavy outline, which fit closely

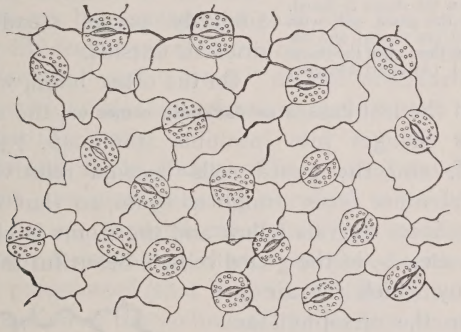


FIG. 70.—Epidermis with stomata from the lower surface of the leaf of *Helleborus niger*. (× 120.) (After Strasburger.)

together (like the blocks of a jig-saw puzzle) except at certain places where minute holes, called **stomata**, are left between them. Each stoma is really a chink between a pair of cells called *guard cells*. The guard cells differ from the other epidermal cells in certain important respects: (*a*) they contain chloroplasts, and therefore can make food, whereas the remaining epidermal cells are colourless and transparent, and are incapable of photosynthesis*; (*b*) their peculiar shape (seen in Figs. 70 and 71) and certain ridges on their walls, cause them to change in form according as they are distended with cell-sap or not. As the soluble sugar accumulates in the guard cells, each absorbs water by osmosis and becomes curved in such a manner as to separate more and

* In fern leaves all the epidermal cells contain chloroplasts.

more from its fellow, until the chink (stoma) between them is widely opened, and there is free communication between the outside atmosphere and the air in the intercellular spaces of the leaf. Constant interchange between the two takes place through the stomata, tending to equalise their composition. Thus, fresh carbon dioxide streams in to take the place of that used in photosynthesis; the surplus of oxygen produced in photosynthesis streams out*; and water vapour from the nearly saturated air of the intercellular spaces similarly passes steadily to the drier air outside.

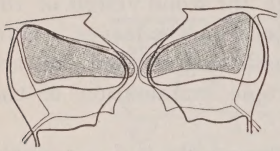


FIG. 71.—Stoma of Hellebore in transverse section. The darker lines show the shape assumed by the guard cells when the stoma is open, the lighter lines when the stoma is closed. The cavities of the guard cells with the stoma closed are shaded, and are distinctly smaller than when the stoma is open. (× 660.) (After Strasburger.)

On the other hand, when photosynthesis in the leaf ceases **as darkness comes on**, the sugar in the guard cells changes into insoluble starch (p. 73), water is drained off, and the guard cells become relatively flabby. Their curved inner faces straighten again, so that each comes into close contact with its fellow and the stoma is closed. The leaf thus possesses, in the guard cells, a beautiful self-regulated apparatus by which the air is admitted to the mesophyll as soon as the conditions are suitable for photosynthesis, and is shut out as soon as conditions become adverse. The closing of the stomata practically puts a stop, not only to photosynthesis, but also to transpiration, since the outer layers of the surface walls of the ordinary epidermal cells consist of cuticle which is practically air-tight and waterproof, and acts as a macintosh covering to the leaf. The only direct communication between the mesophyll and the outer air is through the stomata.

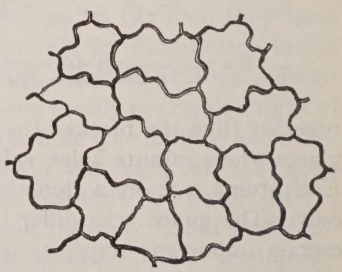


FIG. 72.—Surface view of the epidermis from the upper side of a leaf of *Mercurialis perennis*. (× 300.) (After H. Schenck.)

* Only a small proportion is used in respiration.

The stomata of most leaves are confined to the lower surface and are thereby less likely to be choked with dust, but there are many exceptions to this rule. The following table,* showing the number of stomata per square millimetre in the upper and lower epidermis respectively of a few selected leaves, is instructive:

	Upper	*Lower*
Lilac	100	150
Oak	0	346
Apple	0	247
Water lily	460	0
Wheat	47	52

It will, of course, be remembered that only the upper surface of the water-lily leaf is exposed to the air (Fig. 183), and that the terms "upper" and "lower" do not necessarily describe the actual positions of the surfaces of such "erect" leaves as those of wheat (Fig. 308).

Sun plants and shade plants.—The greatest development of palisade tissue (the main function of which is photosynthesis) is found in leaves exposed most freely to sunshine; while spongy mesophyll (which is chiefly concerned with transpiration) is most pronounced (that is, the intercellular spaces occupy a larger proportion of the volume of the leaf) in plants growing in moist and shady situations.

EXERCISES VI.

1. Draw and describe a typical cell from an actively growing part of a plant.

2. What is osmotic pressure? How is it caused in living cells?

3. Describe the effects of salt water upon a single plant cell. Account for these effects as far as you can. (L.M. part question.)

4. Describe and explain the result of immersing a slice of raw potato alternately in brine and pure water.

5. What are plastids? In what regions of a plant do the different kinds of plastids respectively occur?

6. Describe the principal forms of cells occurring in the packing tissues, conducting tissues and strengthening tissues respectively of a herbaceous plant.

* From Bower's *Botany of the Living Plant* (Macmillan).

7. Draw a diagram of a transverse section through a foliage leaf, showing the epidermis, the cuticle, a stoma, the mesophyll, a vascular bundle, and air-spaces. Only a few cells of each tissue are to be drawn in detail.

8. Describe the structure of a foliage leaf with special reference to the function of transpiration. What are the chief modifications that restrict transpiration ? (J.M.B. Hr. Sch. Cert.)

9. Describe carefully the structure of a stoma. How does it work and what are its functions ? (J.M.B. Hr. Sch. Cert.)

CHAPTER VII.

THE PLANT AND THE SOIL.

14. THE SOIL.

PRACTICAL.

1. The solid particles of soil.—(*a*) Shake up about 10 grams of various kinds of soil with distilled water in a measuring cylinder, allow to settle, and notice the formation of successive layers, which merge into one another. Distinguish in order the slowly settling dark *humus* (at the top); the fine *clay*; the *silt*; and the coarse particles of *sand*, limestone or chalk, and *gravel* (at the bottom). Estimate the relative proportions of these layers in each of your samples of soil.

(*b*) Shake up a second portion of soil with water and then add lime-water. Notice that the water clears much more quickly than before.

(*c*) Test a little of each soil with dilute hydrochloric acid; any effervescence indicates chalk or limestone.

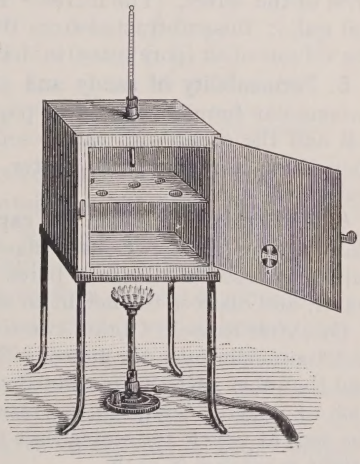


FIG. 73.—Air Oven, heated by rose burner.

2. The amount of water in soil.—Weigh out ten grams of soil in a porcelain dish, and keep it for several hours in an air-oven (Fig. 73) at a temperature of about 100° C. (stirring carefully at intervals with a glass rod) until the weight becomes constant. The loss of weight in grams, multiplied by ten, is the percentage of

water contained in the soil. Compare especially a sandy and a clayey soil on a dry day. Which contains more water?

3. The amount of organic matter (humus) in soil.—Heat the dry soil of Expt. 2 over a Bunsen burner to dull redness until it ceases to lose weight (Fig. 74). The loss in grams, multiplied by ten, indicates the percentage of organic matter present.

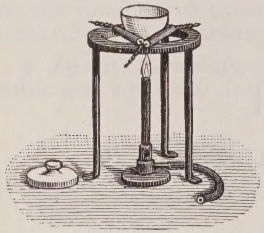


FIG. 74.—Method of finding the proportion of organic matter present in soil, etc.

4. The amount of air in soil.—Find the volume of water required to fill a small tin box (*e.g.* a small cocoa tin) which has not a flanged edge. Then punch a few holes through the bottom (to let air escape), and drive it, mouth down, into the soil to be tested, until it is just full of soil. Remove the vessel, scrape the soil flush with the edge, and then carefully empty it into a measuring cylinder containing a known volume of water. Stir till all air bubbles have escaped, and then note the level of the water. The increase in volume is the volume of the soil only; this subtracted from the capacity of the tin vessel is the volume of air (pore space) in that soil. Calculate the percentage.

5. Permeability of sandy and clayey soils compared.—Fit up two similar funnels with filter papers; half fill one with sandy soil and the other with clayey soil, put a beaker under each, and then fill each funnel with water. Compare the rates at which water runs through.

6. Absorption of water by capillarity.—(*a*) Soften a piece of glass tubing in the Bunsen flame and draw it out to form capillary tubes of different bores. Dip the ends of these into water, and observe the height to which the water rises in each.

(*b*) (After Russell) Obtain two similar transparent lamp-glasses, and tie muslin over the bottom of each. Fill one with dry *sand* and the other with dry powdered *clay*, and stand each in a shallow dish of water. Compare the rate (seen by changes of colour of the soil) at which the water rises through sand and clay, and the height it reaches in each.

7. Retention of water by soils.—When the water in Expt. 6 ceases to rise, lay the two lamp glasses on their sides close together, and observe whether the sand or the clay dries sooner.

8. Presence of soluble matter in soil.—Shake up about ten grams of garden soil in 50 c.c. of distilled water; filter, and

evaporate the *clear* filtrate to dryness in a dish over a water bath. Notice the residue.

Soil.—From the soil, plants obtain the water and the mineral matter which are combined with carbon dioxide in the leaves to make food. From soil they also obtain a considerable amount of oxygen for respiration. We have, therefore, to inquire in what respects the soil is fitted by its composition and texture to supply the plant with these necessities of life.

Only the top six or eight inches of the ground is directly useful to plant life in general, and this portion, the soil proper, ought to be distinguished from the underlying *subsoil*, which is intermediate in character between the soil and the rock from which they have both been derived. Soil, however, is rock material so changed by countless ages of exposure to the pulverising action of rain and wind, sunshine and frost, and by the vital activities of generation after generation of plants and animals which have lived on and in it, that it has acquired special properties.

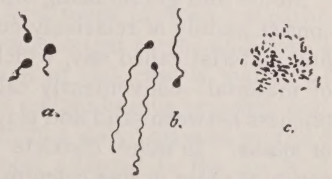


FIG. 75.—Three kinds of nitrifying bacteria. (× 1000.) (After Winogradsky.)

The essential difference between true soil and mere rock-debris is that the former contains a complex, dark brown organic material called **humus**, which consists of the partly decayed remains of plants and animals, while the latter does not. The slow rotting of the humus is really a process of oxidation or burning, for which air is needed and during which heat is liberated. Vast numbers of invisible living things * inhabit the humus, and break it up, forming carbon dioxide, water, and various salts which are absorbed by the roots of plants and worked up into food in the leaves (footnote, p. 119). Moreover, humus has certain special properties, possessed only by substances in what is called the **colloid** † state, which add to its

* "The number of organisms in one gram of soil—no more than a teaspoonful—often well exceeds 40 millions" (Russell).

† *i.e.* glue-like. Other colloids are gelatin, white of egg, starch paste, etc.

importance in the soil; that is to say, it is slimy, it absorbs and holds water, it increases the plasticity of clay, and it attracts and sticks tenaciously to certain mineral substances (salts of potassium, ammonia, etc.) dissolved in the soil-water, so that they are not so readily washed out and lost. The humus, though an essential part of true soil, is, however, usually present in small proportion only, perhaps 5 per cent.

The greater bulk of the soil consists of a mixture of **inorganic particles** derived from the wearing down of rocks by the weather. These vary enormously in size, from pebbles and gravel to impalpable dust. They can be separated with sieves of different mesh; or roughly by stirring up some soil in water and allowing it to settle, when they arrange themselves according to size, the larger pieces sinking first and collecting at the bottom of the vessel.

Stones and gravel being omitted, a typical soil is thus seen to consist mainly of relatively coarse particles called **sand**; of very fine material called **clay**, which settles very slowly indeed; and of material—conveniently called **silt**—which is intermediate in fineness between sand and clay; as well as of the organic matter or **humus**. In many districts the soil is calcareous, that is, it contains more or less calcium carbonate (**chalk** or **limestone**).

Classification of soils.—Soils containing not more than 6 per cent. of clay, the rest being chiefly sand and silt, are called **sandy soils**. If 25 per cent. or more is actual clay, the soil is described as a **clayey soil**, or as a "clay." If the soil contains too much clay to be described as sandy, and too much sand to be called a clay, it is a **loam**. Sir E. J. Russell describes a loam as a soil containing 6 to 15 per cent. of clay, 40 to 60 per cent. of the silts, and 20 to 50 per cent. of coarse and fine sands. If a considerable amount of calcium carbonate is present as well, the soil is called a **marl**.

Clay and sand compared.—Clay and sand have very different properties, so that their relative proportion in any soil has a far-reaching effect on the plants growing in it. **Clay** is a colloid, and therefore, like humus, retains water very tenaciously, fixing certain dissolved salts, and binding the other constituents of the soil together. In excess, it makes the soil "heavy," that is, difficult to dig or plough, and also interferes

with the free movements of water and air, which are necessary for healthy root development. Moreover, it will be clear (in view of the high specific and latent heat of water) that a clay soil will be kept relatively cold, because the stagnant water present absorbs solar heat which would otherwise have warmed the ground. On a cold soil, crops tend to ripen late. An excessively clayey soil is improved by the addition of (*a*) lime, which causes the fine particles of clay to "flocculate" or stick together in flakes (Expt. 1, *b*, p. 107) and also neutralises any acidity; (*b*) farmyard manure, which makes the soil more open in texture; and (*c*) phosphates (p. 119).

Sand, on the other hand, does not stick together, and is open in texture, allowing the free percolation and escape of water and the circulation of air. When sand is present in excess the soil becomes too dry by drainage (with loss of dissolved salts) and free evaporation. Corn grown on such land tends to ripen too early. These defects may be remedied to some extent by the addition of well-rotted farmyard manure (which in this case is mainly of service by increasing the amount of colloid humus present), and of potash manures (p. 117). Evidently a duly balanced mixture of clay and sand (*i.e.* a loam) is best adapted to the needs of the plant, and loams are on the whole the most fertile soils.

Available water.—It will be obvious from the above that a plant will in general be able to obtain much more water from a sandy soil than from a clayey soil containing an equal amount of water, because the former parts with its water so much more readily. Even a sandy soil, however, may retain 2 per cent. of water of which plants cannot deprive it, while a heavy clay soil may be "dry," so far as plants are concerned, and still contain 20 per cent. or more water.

Pore space in soil.—The solid particles of good soil are thus separated by air (which in a normally moist soil may occupy from 25 to 50 per cent. of the volume), so that the whole has a spongy texture. The grains of sand and silt form as it were the supporting frame-work, and are coated by "gels" (*i.e.* slimy films) of colloid clay and humus, in the moisture of which are dissolved the salts needed by the plant for food-making. The films swarm with nitrifying (nitrate-making) and other

micro-organisms. Rain soaks readily into such a soil, displacing the air but being itself displaced by fresh air as it drains away,

FIG. 76.—Diagram of soil, penetrated by root-hairs. The films of moisture coating the soil particles are shaded; air spaces are shown by clear areas. *e*, cells of surface layer of root, from which the root-hairs, *h*, grow out between the particles of soil. (After Sachs.)

leaving the mass neither waterlogged nor unduly dry. The water evaporating from the surface is replaced by water flowing from the deeper layers by **capillary action** (p. 108) through the fine passages of the soil, so long as these channels are undisturbed and the films of moisture therefore remain continuous. It is easy to understand that the farmer's and gardener's practice of hoeing the surface of the soil in hot weather checks evaporation by interrupting the continuity of the films of moisture and therefore stopping the capillary flow.

15. THE PLANT'S SUPPLY OF MINERAL MATTER.

PRACTICAL.

1. A plant cannot grow permanently in damp sawdust or clean sand.—Compare the progress of seedlings grown in damp sawdust, cocoanut fibre or moss, as in Chap. III., with that of similar seedlings grown in soil. Notice that the plants in soil flourish while the others presently wither and die. Obtain some clean sand, and, to make sure it contains nothing which water can dissolve, wash the sand in several changes of clean water and finally in distilled water. Germinate some seeds in the sand, keeping it damp, and notice that these seedlings also fail to thrive.

2. The amount of water, organic matter, and mineral matter in seeds and in the resulting plants.—Select three bean seeds A, B, and C, as nearly as possible of the same weight, and record the weight of each. Next, soak them in water until soft. Put A, cut into thin slices in a weighed dish, into an air oven (Fig. 73), and dry without scorching until the weight is constant. Record this " dry weight." Ignite the dried slices carefully at a dull red heat (by a small Bunsen flame) in a weighed porcelain crucible without lid (Fig. 74), until nothing is left but grey ash. Record the weight of ash.

Plant seed B in damp sawdust or well-washed sand, and seed C in ordinary soil. When plant B seems on the point of failing (Expt. 1), take up B and C, carefully wash the roots clean, remove any adhering water by dabbing with a dry cloth or blotting paper, and weigh each plant. Then cut each into small pieces, dry in the oven without scorching, find the " dry weight " of the plant and (by difference) the uncombined water present in it.

Ignite the dry pieces of each plant separately and record the weight of the ash obtained.

Tabulate your results as follows, filling in the blanks.

	A (seed only)	B (plant in washed sand)	C (plant in soil)
1. Total weight of unsoaked seed -			
2. " Dry weight " of seed - -		——	——
3. Uncombined water (by difference) in unsoaked seed -		——	——
4. Ash in seed -		——	——
5. Total weight of plant - -	——		
6. " Dry weight " of plant - -	——		
7. Uncombined water (by difference) in plant - -	——		
8. Ash in plant -	——		

Compare especially the quantities A4, B8, and C8; A2, B6, and C6; B6 and C6-C8. [If convenient (*e.g.* when a number of pupils work together) the results obtained from several specimens of A, B and C should be averaged.]

Find also the percentage of water and ash in a lettuce, and in any small woody plant or the branch of a tree.

[Students who are taking or have taken chemistry should test plant ash (*e.g.* ash from firewood) for sodium, potassium, sulphates and phosphates.]

3. Knop's nutritive solution.—Make up the following mixture of salts :

Potassium nitrate - -	1 gram
Potassium phosphate - -	1 gram
Magnesium sulphate - -	1 gram
Calcium nitrate - - -	4 grams

Add one or two drops of iron chloride solution, and shake up with two litres of distilled water. Immediately before the solution is used it should be boiled for twenty minutes and cooled, the water which has boiled away being replaced by freshly boiled distilled water. A slight precipitate will be produced, and therefore the bottle should be shaken before the culture jars are filled.

4. Water culture.—Obtain a number of jars (*e.g.* jam jars) or wide-mouthed bottles, holding about one litre. Fit each with a wooden lid provided with one or more slots for holding seedlings, and with a glass tube reaching nearly to the bottom of the jar to allow daily aeration of the liquid with a bicycle pump. Wash the jars with strong nitric acid, then with tap water, and finally with recently boiled distilled water, and drain. Bake the lids in an oven, or pass the flame of a Bunsen burner over their lower sides several times to ensure absence of moulds, etc., and fit the plants in the slots (by packing with baked cotton wool) at such a height that only the roots will dip into the solution.

Charge the jars with solution, put on the lids and insert the aerating tube, which should be plugged loosely with cotton wool to keep out dust. If the jars are of glass they should be covered with brown paper to keep out the light. Care must be taken to keep the lids and cotton wool dry. Add freshly boiled and cooled distilled water from time to time to replace loss by evaporation, and bubble air through daily with a pump.

Suitable plants are young seedlings without much reserve food (*e.g.* poppy or wallflower germinated not in soil, but in clean washed sand), or cuttings of fuchsia, willow, etc.

5. Plants deprived of all mineral matter.—Keep *similar* plants with their roots dipping in distilled water, but in all other

respects under the same conditions as the above, and compare the progress of the two sets.

6. Plants deprived of essential elements.—Make up different solutions from each of which *one* of the elements in Knop's solution is omitted : *e.g.* (*a*) leave out the iron chloride only, putting in sodium chloride instead ; (*b*) substitute calcium chloride for calcium nitrate, and potassium sulphate for potassium nitrate ; (*c*) substitute sodium nitrate and sodium phosphate for potassium nitrate and potassium phosphate ; (*d*) substitute magnesium nitrate for calcium nitrate. Label (*a*) " without iron," (*b*) " without nitrogen," (*c*) " without potassium," (*d*) " without calcium."

Make drawings and notes of the effects on the plants in Expts. 5 and 6.

The plant's need for mineral salts.—In the work of Chapter IV. we found abundant evidence that a plant makes its carbohydrate food in certain places only, *i.e.* in its green parts (generally leaves) ; and only when these green parts are supplied with certain materials (carbon dioxide and water), and live under certain oonditions of light, temperature, etc. Plants may be raised from the seeds in damp washed sand, in circumstances ensuring all the necessities just mentioned, and they will develop satisfactorily for a limited time. Such a plant dried in the oven (to rid it of all uncombined water) will be found considerably heavier than a dried ungerminated seed : a fact which shows it has added to its solid substance, though nothing but air and water can have entered it from outside. This new substance is plainly the result of photosynthesis (p. 72).

If, however, such a plant be burned to ash after drying, no more ash will be obtained from it than from one of the ungerminated seeds. Evidently the amount of mineral matter in the plant has *not* increased during its life in the damp washed sand ; and this may be why—as soon becomes apparent—such plants languish and die when the food originally present in the seeds is exhausted.

The surmise that plants need to be supplied not merely with carbon dioxide and water, but also with mineral matter, is confirmed by burning a plant of the same stage of development as that considered above, but grown in ordinary soil. It will be

found that it yields much more ash. The plant's need for mineral matter may be proved conclusively by the method of water cultures next to be described.

Water culture.—The water extracted from very many soils has been analysed, in order to find out which of its dissolved constituents are needed by plants. Even the water from cultivated land is a very dilute solution of various salts, some of which are necessary and others unnecessary. Common salt (sodium chloride), for example, is found in all soils, and is absorbed by plants, but does not appear to be essential. This fact and others of much greater importance have been discovered by what is called "water culture." In such experiments plants are grown with their roots not in soil, but dipping into different solutions of known composition, and the effects on the plants are carefully watched and compared (Fig. 77). Various precautions are necessary to ensure success; the most important of these are mentioned in the instructions on p. 114.

Knop's solution.—Knop's solution contains the following salts in two litres of pure water: one gram each of potassium nitrate, potassium phosphate and magnesium sulphate, four grams of calcium nitrate, and a trace of iron chloride. Seeing that most plants will flourish when supplied only—so far as material substance is concerned—with this mixture and air, it evidently contains all the mineral matter usually necessary for complete nutrition, and is worth careful study. Plainly, the **non-metals** present in the solution are: oxygen, hydrogen, nitrogen, sulphur, phosphorus and chlorine. The **metals** present are: potassium, calcium, magnesium, and iron. It is to be noticed, by the way, that *the solution does not contain any carbon*—a fact which indicates that all the carbon (charcoal) in plants normally comes from the carbon dioxide of the air.

Since plants can grow satisfactorily in Knop's solution, we conclude that the elements enumerated in the preceding paragraph supply all the material needed. The question arises, however, Can any of these elements be dispensed with? The question can be answered by attempting to grow plants in various solutions from each of which *one* different element from the above list has been omitted. Conversely, by using an increased

amount of any particular element we may learn what is its special effect upon plants.

Essential metals.—It is found, for instance, that if instead of iron chloride we put an iron nail into the solution, the plant does not suffer; this shows that chlorine is unnecessary. If, on the other hand, **iron** and all its compounds are carefully excluded, the plant is unable to keep up its necessary stock of chlorophyll, for its leaves become yellow ("chlorotic"), and photosynthesis is interfered with. This is curious, because chlorophyll itself does not contain any iron. Only a very small trace of iron is necessary for the formation of chlorophyll, and leaves suffering from chlorosis soon become green and healthy again if painted with a very dilute solution of iron chloride.

If **potassium** is omitted from Knop's solution (by substituting sodium compounds for the potassium compounds), the plant loses all power of making starch (why, it is not understood), the stem becomes weak, the leaves turn dull in colour and begin to wither at the tips, and the whole plant suffers from lack of tone and readily becomes diseased. It is easily understood that crops grown specially for their yield of starch or sugar (*e.g.* potatoes, sugar beets, etc.) need supplying with manures rich in potassium (*e.g.* kainit). Potash manures neutralise the tendency to mature too early, which is usual with crops on sandy soils (p. 111).

If **calcium** be omitted (by the substitution of magnesium nitrate for calcium nitrate) the roots do not develop well, and the plant as a whole is lacking in vigour.

Magnesium has been found to be an essential constituent of chlorophyll, so that magnesium starvation acts by preventing the formation of new chlorophyll in the plant, bringing about etiolation (p. 66), and slowing down and finally stopping photosynthesis. The addition of magnesium salts to ordinary soil, however, does not increase the amount of photosynthesis of plants beyond the normal.

Essential non-metals.—We may now consider the non-metallic elements in our culture solution. **Oxygen** is, of course, present in all nitrates, phosphates and sulphates, and with **hydrogen** forms water; so that oxygen and hydrogen are present in abundance.

Nitrogen forms four-fifths by volume of the air, but it is generally supposed that very few plants can use atmospheric

FIG. 77.—Water cultures of field peas. 1, in distilled water; 2, in tap water; 3, in Knop's solution; 4, without nitrogen; 5, without phosphorus; 6, without potassium; 7, without calcium; 8, without magnesium; 9, without iron; 10, without sulphur. (After Duggar.)

nitrogen directly as a source of food. Plants of the family *Leguminosae* (peas, beans, clover, etc.), however, have on their roots certain nodules (Fig. 152) containing microscopic plants called bacteria, which work up the nitrogen of the soil-air into

compounds which the leguminous host plant can use.* If the nodule-bearing roots of a leguminous crop are left to decay in the soil, their surplus of nitrogen compounds becomes available for succeeding plants. Leguminous plants thus make soil richer in available nitrogen instead of exhausting them in this respect, as other crops do.

Normally, plants obtain their nitrogen supplies largely from *nitrates* and *ammonium salts*, built up by certain micro-organisms (nitrifying bacteria) from the decomposing humus which they inhabit (p. 109).† Such humus, as we know, consists of the remains of former plants and animals, so that the nitrogen is really used over and over again, apart from what is washed out of the soil by rain or taken away in the form of crops. Plants suffering from nitrogen starvation (as in Expt. 6, *b*, p. 115), are of very stunted growth, the leaves being poorly developed and turning yellow. When nitrates are in excess, rich green leaves are developed in abundance, but flowering and seed-production are delayed. For this reason, manuring with nitrates is more freely practised in growing plants for the sake of their leaves (*e.g.* cabbages, lettuce, spinach) than in the cultivation of fruits (wheat, barley, tomatoes, etc.).

The lack of **phosphorus** in a water culture does not obviously interfere with the growth of a plant during the short period of time for which such an experiment usually lasts. Considerable differences have been found, however, between crops plentifully supplied with phosphates (the compounds from which plants normally obtain phosphorus) and other plants deprived of phosphates. The most remarkable effects of the application of phosphates (*e.g.* as basic slag) to the soil are, *first*, to increase the

* It has been asserted that not only the nodule organisms on the roots of Leguminosae, but also many other plants, use the free nitrogen of the atmosphere to build up nitrites and nitrates and form organic nitrogenous compounds, and that wheat plants can fix nitrogen from the air in amounts up to 21 per cent. of the total nitrogen content of the plant (*Nature*, Jan. 20, and Feb. 10, 1923).

† In the decomposition of humus, the nitrogenous compounds present are first decomposed with the formation of *ammonia*; this is converted by bacteria first into *nitrites* and afterwards into *nitrates*. These nitrifying bacteria cannot function in acid soils.

development of the root system (hence their use in growing turnips, swedes, etc., and also in stiff clay soils—where roots cannot spread easily); and, *secondly*, to hasten the ripening of fruits (*e.g.* wheat grains), which tends to be delayed in cold wet soils. Obviously phosphates should be used with caution on light sandy soils, where the conditions are precisely opposite.

Plant protoplasm is an extremely complex combination of carbon, oxygen, hydrogen, nitrogen, phosphorus, and sulphur. All these are necessary for the life of the plant, since without them the renewal or increase of living substance is obviously impossible. The other essential elements apparently do not form part of the actual building material of protoplasm, but are necessary in various ways to enable the protoplasm to carry on its activities.

Farmyard and artificial manures compared.—While artificial manures supplying nitrogen, phosphorus and potash are valuable helps to the farmer, the superior effect of farmyard manure

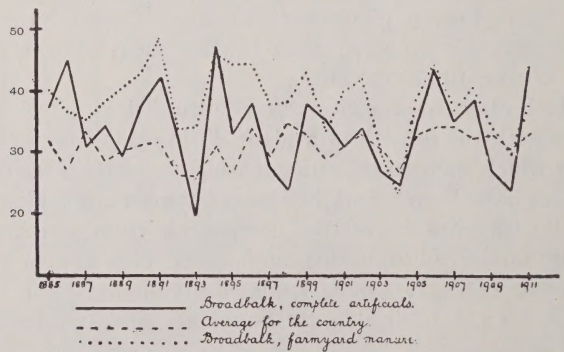


FIG. 78.—Yields of wheat (bushels per acre) from plots of the Broadbalk Field, Rothamsted, manured with complete artificial manures and farmyard manures respectively, compared with the average yield for the whole country, 1885 to 1911. (From *Nature*, after Russell.)

is strikingly shown in Fig. 78. Much of the difference is no doubt caused by the improvement which farmyard manure brings about in the *physical* condition of the soil (p. 111), but probably it is mainly due to the stimulating effect of certain chemical substances produced in the intermediate stages of decomposition of the humus by the micro-organisms of the soil.

Rotation of crops.—When plants die and decay where they grew—as is the case where vegetation is left to itself—or when land is continually grazed by cattle or sheep, the mineral matters which the roots take from the soil are for the most part returned to the soil and are rendered available for succeeding plants. But when any particular crop is grown and *removed*, the soil is thereby deprived of certain mineral salts; and unless these are somehow made good, repetition of the process will sooner or later impoverish the ground to such an extent that it can no longer support the crop in question.* The loss can be made good (1) by the application of manures providing similar salts, as well as (2) by the growth of crops *having different needs* and habits, to enable the soil to recuperate itself without lying fallow. It is partly with this latter object that rotation of crops is practised in agriculture. Thus, in the well-known **Norfolk rotation**, clover or some other leguminous crop (p. 118) is grown once every four years and the roots are ploughed in; the soil is thereby enriched in nitrates. Wheat is usually grown next, and after wheat a crop of "roots" (turnips, swedes, mangels, potatoes), which, as the plants are low and well spaced, affords a needed **opportunity to get rid of weeds.** Roots are succeeded by either barley or oats, according as the soil is light or heavy. Another leguminous crop follows, and the rotation is repeated. It is interesting to note that wheat and barley (though so closely related, p. 417) draw upon different levels of soil for supplies of water and salts, the roots of wheat growing comparatively deeply, while those of barley keep much nearer the surface.

EXERCISES VII.

1. Describe experiments which *you* would carry out to investigate the physical properties of any *one* type of soil, and state what results you would expect to obtain. (C.S.)

2. How would you determine the water- and air-content of a soil? Enumerate the soils with which you are familiar, and state how they differ from one another in their water- and air-content. How would the addition of humus affect the character of (*a*) a sandy soil, (*b*) a clayey soil? (L.M.)

3. How would you roughly analyse garden soil? How would analysis enable you to cultivate your garden more successfully? (Prel. Cert.)

* The yield from an *unmanured* plot of the Broadbalk wheat field at Rothamsted Experimental Station diminishes annually by about half a bushel per acre, and in 1920 was about 12 bushels. (Compare Fig. 78.)

4. Explain what a farmer means by calling a soil "heavy." If you were to make an examination of such a soil in the laboratory, what kind of composition would you expect it to have? (O.S.)

5. Compare clay and sand in regard to their suitability for plant growth. (C.J.)

6. Point out the respective advantages and disadvantages, from the gardener's point of view, of a clay soil and a sandy soil. How would you try to improve each type? Give reasons for the methods adopted. (N.F.U.)

7. Describe some experiments to show that grit or sand, clay and humus are contained in varying proportions in most garden soils.

What statement would you make to children over eleven years of age as to the origin of these constituents, and what out-door observations could be carried out to explain the differences in their proportions? (Cert.)

8. Explain carefully the relations between the physical structure of the soil and the water supply available to plants growing in the soil. (C.S.)

9. What is "sub-soil"? Explain the relative nutritive values of sub-soil and surface soil. (C.J.)

10. What are the factors governing the amount of organic matter in soils? How does organic matter affect the properties of soil? (C.S.)

11. Explain the botanical significance of the frequent hoeing of the soil between growing plants in dry weather.
(C.S. part question.)

12. Contrast the more important effects of stagnant water in soil with those produced by a satisfactory supply of water able to move naturally through the soil. Give point to your remarks by reference to suitable experiments. (Cert.)

13. Soil largely consists of clay, sand, humus and some carbonate of calcium (chalk). State the purpose that each ingredient serves in rendering a soil suitable for the growth of plants.
(Prel. Cert.)

14. Give an account of the various processes by which a growing plant may add to, or diminish, its weight. (O.S.)

15. Describe how *you* would endeavour to find out what mineral salts a plant requires for its growth. (C.J.)

16. State how you would determine experimentally what substances supplied to the roots are essential to plant growth.

How is the supply of these substances in the soil maintained? Why is it necessary to apply manure to land on which crops are grown? (J.M.B. Matric.)

17. Describe carefully how you would carry out experiments in order to determine whether compounds of phosphorus, potassium and iron are essential constituents of the inorganic food materials of green plants. What precautions would you take in setting up the experiments ? (O.S.)

18. From what source does a green plant obtain its supplies of nitrogen ? In what form and where are they taken in by the plant ?

19. In what state of combination is nitrogen usually absorbed by the plant ? How are the compounds referred to produced in soil ? How can a farmer assist in the production of these compounds ? (O.S. Applied Sc. D.)

20. What do you understand by a " food " ? What are the chief plant foods ? From what inorganic materials are these foods manufactured ? (O.S.)

21. What do you understand by rotation of crops ? Outline the principal facts of plant nutrition which underlie this method of cultivation. (J.M.B. Hr. Sch. Cert.)

CHAPTER VIII.

ROOT STRUCTURE AND THE ABSORPTION OF WATER.

16. THE STRUCTURE OF THE ROOT.

PRACTICAL.

1. The region of elongation.—Germinate pea and bean seeds until the radicles are about an inch long. Lay one or two on a flat ruler and mark the radicles at equal intervals (*e.g.* $\frac{1}{10}$ inch) with waterproof Indian ink by means of a fine brush. Draw the seedlings and return them to damp sawdust for a few days, and then measure the intervals between the marks to see which parts of the radicle have grown most and which least. Draw. Compare with other seedlings of the same stage which show root hairs, and mark the position of the hairs on the drawings. Do any hairs grow on the elongating region ?

2. Force exerted by elongation.—Pin a weighed bean seedling through the cotyledons to a cork clamped just above a letter balance, so that the radicle is vertical and its end fits loosely into a hole bored in a small cork fixed by wax to the top of the balance. Keep the seedling covered by damp cotton wool. Note the force of downward growth, and compare it with the weight of the seedling.

3. Branching.—Draw stages of bean seedlings, showing increasing numbers of branches. In what order do subsequent branches follow the first ? Do branches grow on the elongating, or on the hair-bearing, regions of the root ? Do the branches grow from the surface or from the interior of the radicle ? Do the branches form rows (look at the root " end-on " to see this) ? Do the branches themselves branch ? In what respects do the branches (*a*) resemble, (*b*) differ from, the part from which they spring ?

4. Root hairs.—Pull up seedlings growing in soil and compare them with others grown in damp sawdust. To which part of the root does the soil cling most ? Is the soil easily washed off ?

Explain. Similarly examine older plants with a branched root system.

5. Tap roots and adventitious roots.—Examine the roots of as many plants as possible, and note whether the roots consist of (*a*) a branching main (tap) root ; (*b*) a cluster of roots of apparently equal importance, springing from the base of the stem. In each case notice (by the venation of the leaves, p. 52) whether the plant is a dicotyledon or a monocotyledon.

6. General structure of roots.—Examine with the low power of the microscope, or with a lens, entire roots of mustard or cress seedlings that have been grown in damp blotting paper. The root should be mounted in water and covered with a large cover-slip without including air bubbles. Make drawings to show (*a*) the *root-cap*, (*b*) the *root hairs*, (*c*) the *central cylinder* (a core running down the middle but becoming indistinct near the tip) ; (*d*) the *cortex*, between the central cylinder and the surface ; (*e*) one or more young *branches* (note their origin from the central cylinder and the continuity of their central cylinders with that of the main root).

7. Longitudinal sections.—With a very sharp knife or a razor split the tap root of an advanced bean seedling down the middle from end to end. Study with a lens the origin of any rootlets cut through and notice that they arise from the central cylinder. Make thin longitudinal sections with a water-wetted razor at various levels (*e.g.* the origin of a rootlet, the hair-bearing region, and the parts just above and below this), mount in water and examine with the microscope.

*** 8. Transverse sections.**—(*a*) *Buttercup root.*—With a water-wetted razor cut thin transverse sections of a buttercup root, holding it for support between pieces of pith. Treat with aniline sulphate (p. 491), mount in water and examine with the microscope. Identify—from outside to centre—(i) the *piliferous* (hair-bearing) *layer* : the hairs themselves have probably been destroyed by handling ; (ii) the broad *cortex*, with intercellular spaces : the innermost layer of cortical cells has thick cell walls, and surrounds (iii) the *central cylinder*. In (iii) observe the four-rayed tissue of the xylem or wood, consisting chiefly of circular vessels, the walls of which are stained yellow by the aniline sulphate. The tissue between the rays is the phloem or bast.

(*b*) *Bean root.*—With a water-wetted razor cut thin transverse sections through various levels of an advanced root of a kidney bean

* May be omitted on a first reading.

seedling, including one or more through the origin of a rootlet, and through the region bearing root-hairs. Mount the sections in order of age (*i.e.* of distance from the tip) in a drop of aniline sulphate solution, and distinguish (i) piliferous (hair-bearing) layer, (ii) cortex, (iii) central cylinder. In (iii) observe that in the younger regions the woody tissue (stained bright yellow by the aniline sulphate) is in groups or rays equal in number to the rows of rootlets (4-6), but in the older parts it has been added to by later-formed vessels (secondary wood). Trace the continuity of the wood of a branch with the wood of the main root.

In the oldest parts of the root, the cortex and piliferous layer dry up and are shed (examine intermediate sections to see the stages), so that the old roots consist only of the central cylinder, the outer layer of which has become corky.

(*c*) *Hyacinth or onion root.*—Cut sections as in (*a*) and identify the regions as before. Note that there are about six xylem groups alternating with the same number of phloem groups.

The main regions of the root.—From end to end a typical root has three main regions. (1) The **elongating region** of the root is only a *short* portion immediately behind the tip, as may be proved by marking it with equidistant dots and noticing to what extent their distance apart alters in the next few days (Expt. 1, p. 125). Just behind this elongating region—which is smooth and slimy—the root is anchored firmly in the soil by fine hairs (root hairs) growing on its surface and clinging closely to the particles of soil. The result is that no buckling is caused by the elongation, in spite of the great force needed, and exerted (Expt. 2, p. 125), in overcoming the resistance of the soil, and the lubricated tip is driven steadily forward. Further, the tip itself is protected by a thimble-like **root cap** which, naturally, is worn away rapidly by friction with the soil it is forced through, but is replaced as rapidly by the active production of new cells at the root tip which it covers.

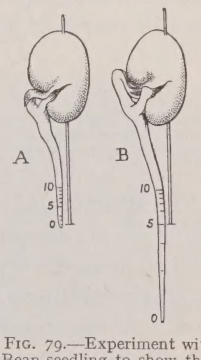


FIG. 79.—Experiment with a Bean seedling to show that the growth in length of a root takes place just behind the tip. In *A* the root-tip has been marked by equidistant lines. *B* shows the same root after 22 hours. ($\times \frac{1}{2}$.) (After Sachs.)

(2) Behind the elongating region comes a length of, at most, one or two inches, clothed for the time by root hairs. This is the all-important **absorptive region**, for it is here, and here only, that any appreciable amount of water enters. The region of absorption is always changing, moving on; for it is always the part which has just ceased to grow in length. As new hairs are thus constantly appearing on this part, the old hairs are dying off behind, as the part which bore them ceases to absorb. (3) From thenceforward this part is the **supporting and conducting region** of the root. In most dicotyledons it grows in thickness and produces branches which pass in their turn through similar phases of activity.

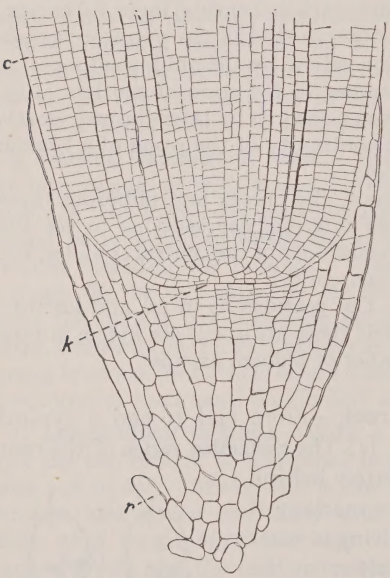


FIG. 80.—Longitudinal section of the root-tip of Barley. *k*, growing point; *r*, a cell of the root-cap; *c*, piliferous layer. (× 150.) (After Strasburger.)

The structure of the root.—The main internal features of root structure are simple, and may be most easily studied in the part clothed by root hairs. They are well seen in Fig. 81. The outside layer, since it bears the hairs, is called the **piliferous** (hair-bearing) **layer**. A low power of the microscope shows that the hairs are merely certain cells of this layer which have become enormously extended. The piliferous layer is not a skin or epidermis, such as is found to clothe stems and leaves, for its cells are specialised only in their tendency to grow out and form hairs.

Next comes a broad band of tissue called the **cortex**, composed of loosely packed egg-shaped cells. Between these cortical cells are abundant *intercellular spaces filled with air*, to which the air

of the soil has free access between the cells of the piliferous layer. The innermost layer of the cortex (the *endodermis*) is composed of cells which fit quite closely together, however, so that the air spaces of the cortex are shut off from the remaining portion of the root—the central cylinder—and nothing can pass from cortex to central cylinder, or from central cylinder to cortex, except in solution.

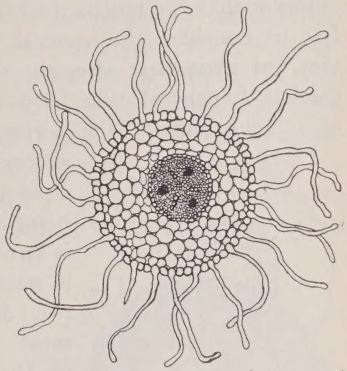


FIG. 81.—Transverse section of young root, highly magnified. Notice, in the central cylinder, the 3-rayed xylem alternating with the three dark patches of phloem. (After Bailey.)

The **central cylinder**, occupying the middle of the young root as the graphite occupies the middle of a lead pencil, is the part of the root which transmits the absorbed water up to the stem to be forwarded to the leaves, and also receives the leaf-made food from the stem to be distributed to the living cells of the root for their nourishment.*

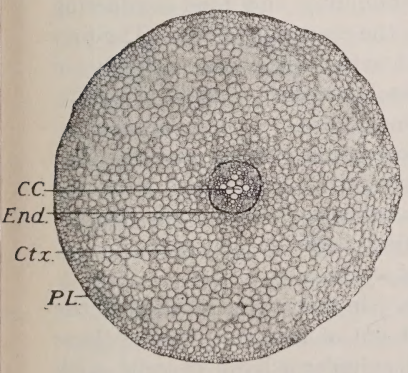


FIG. 82.—Photomicrograph of transverse section of Buttercup root. *C.C.*, central cylinder; *End.*, endodermis; *Ctx.*, cortex; *P.L.*, piliferous layer. (T. D. Tuton Hall.)

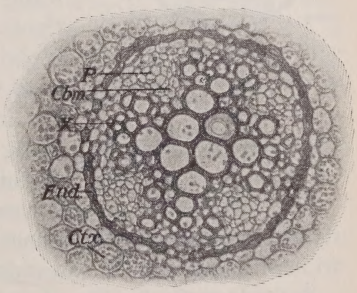


FIG. 83.—The central region of Fig. 82 more highly magnified. *P.*, phloem; *Cbm.*, cambium; *X.*, xylem. (The four original xylem strands have grown together to form a central cross-shaped mass of wood vessels.) *End.*, endodermis; *Ctx.*, cells of cortex, containing starch grains. (T. D. Tuton Hall.)

* It is important to notice that a root does not obtain its food from the soil, but from the leaves. What a root takes from the soil is not food, but material which is made into food in the leaves.

The central cylinder.—Since the water-conducting region is mainly composed of wooden pipes (vessels), it is in the central cylinder that the mechanical strength of the root chiefly resides. Let us consider the central cylinder first from the point of view of **mechanical strength.** It is noticeable (Fig. 82) that the woody central cylinder is a very narrow core in the middle of a thick sheath (the cortex) of softer material. This is in accordance with the engineering principle that any structure in danger of being broken by a *pull* along its length is strongest when the resistant material is nearest the middle. It is precisely this danger to which roots would be most exposed, by the swaying about of the stem and foliage above, if it were not for the concentration of their strengthening tissue in the middle line (contrast stems, p. 167).

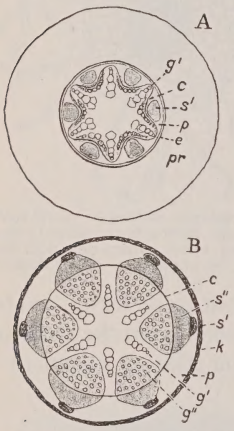


FIG. 84.—Growth in thickness of a typical dicotyledon root, as seen in transverse section. *A*, before, *B*, after thickening has begun. *pr*, cortex; *c*, cambium ring; *g'*, primary xylem (wood); *g''*, secondary wood; *s'*, primary phloem (bast); *s''*, secondary bast; *p*, pericycle; *e*, endodermis; *k*, bark. (After Strasburger.)

The **conducting tissue** of the young root is arranged in *alternating* strands of water-conducting and food-conducting tissue in the central cylinder. The first is called **xylem**; it consists chiefly of dead vessels or pipes of *wood* (Fig. 67), but includes also a certain number of living woody cells of other shapes. The machinery which brings food from the leaves is believed (p. 156) to be the soft tissue called **phloem** or *bast*, consisting chiefly of sieve tubes (p. 99), which lies between the strands of xylem.

Secondary thickening of roots.—In transverse sections of the young roots of dicotyledons, but not of monocotyledons, there may also be seen in the central cylinder a band of cells, with very thin walls, on the outer side of each xylem strand and the inner side of each phloem strand (Figs. 83 and 84). This tissue is called **cambium.** Its cells have the remarkable power of dividing indefinitely to produce new tissue, which gradually becomes modified to form additional (or secondary) wood on the

inner border of the cambium, and additional (or secondary) bast on its *outer* border.

The activity of the cambium varies considerably at different seasons, being greatest in spring and early summer, less in late summer and autumn, and ceasing altogether in winter. In trees and shrubs, this variation is reflected in the texture of the wood, that formed in spring having wide vessels, whilst the autumn-formed wood has narrower vessels (Fig. 85). To the naked eye this difference in texture is visible in woody roots cut across, as **annual rings**, similar to those found in woody stems (p. 155). In most other respects as well (*e.g.* medullary rays) an old tree root is very similar to an old stem, although in their young stages they show several well-marked differences.

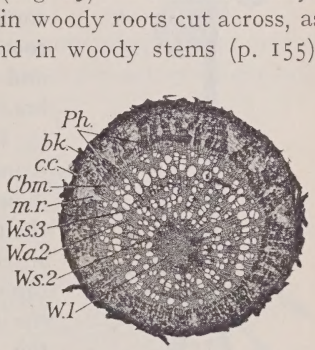


FIG. 85.—Photomicrograph of transverse section of root of Lime in its third year. *W.*1, first year's wood; *W.s.*2, spring wood of second year; *W.a.*2, autumn wood of second year; *W.s.*3, spring wood of third year; *Cbm.*, cambium; *m.r.*, medullary ray; *c.c.*, cork cambium; *bk.*, bark; *Ph.*, bast. (× 16.) (T. D. Tuton Hall.)

Cork and bark.—The accumulation of new material (much of it hard wood) which goes on inside the central cylinder of a thickening root, naturally causes stretching, and ultimate tearing, of the tissue of the cortex outside. This would expose the plant to various dangers were it not for the fact that, before the tearing takes place, a layer of **cork** is produced in the outer part of the central cylinder. Cork, as everyone knows, is air-tight, water-proof and elastic, and the central cylinder is therefore protected from being injured when the cortex tears. The cortex, however—its work finished—being shut off by the cork from the food supply, dies and withers, and eventually peels off. The cork layer, with the dead layers outside it, forms what is called **bark**. The older part of the root, therefore, consists of the more or less bark-covered central cylinder only, which may continually increase in thickness so long as the tree lives.

Branching of the root.—In the meantime, **rootlets** have been developing in this thickening part of the root, and growing out

more or less horizontally to explore the soil on all sides (Fig. 86). In structure the rootlets resemble the main root in all respects, and are therefore called branches* of the main root. The branches spring *from the central cylinder*. They are therefore said to **arise endogenously** in contradistinction to the branches of stems (p. 147), which arise exogenously (*i.e.* from the "outer" or cortical tissues). The branches of the root eat their way through the cortex, and at last their cap-covered ends break through the surface. They appear in strict order of age, the youngest being always nearest the tip of the main root.† The secondary rootlets in their turn bear "tertiary" branches. In this way by repeated branching the tap-root system is able to explore the neighbouring soil very thoroughly, the root hairs of every branch contributing their share of absorbed soil-water for the good of the whole plant.

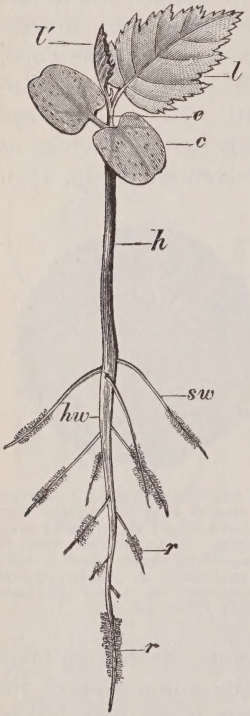


FIG. 86.—Seedling of Hornbeam, with typical branching tap-root. *r*, zone of root-hairs near root-tip; *h*, hypocotyl; *hw*, main root; *sw*, lateral roots; *l*, *l'*, leaf; *e*, epicotyl; *c*, cotyledon. (Nat. size. After Noll.)

Secondary thickening and branching.—It is plain that the original amount of xylem in the tap root alone would soon be insufficient to receive and transmit this continually increasing amount of soil-water—required as the plant as a whole grows in size—and equally plain that the original phloem of the tap root would be insufficient to supply the increasing number of root branches with all the leaf-made food they require. Secondary thickening must thus keep pace with the branching.

We may say then that **the uses of secondary thickening are:**

(1) To provide more machinery (*a*) for the transmission of the

* Compare p. 142.

† This order is called *acropetal* (*i.e.* tip-seeking) succession.

greater supply of soil-water required as the number of leaves increases, and (*b*) for the distribution of the increased amount of leaf-made food needed by all active tissues as the plant as a whole grows larger.

Secondary thickening has important indirect advantages as well, for (2) it provides increased mechanical strength, and (3) it produces a regular supply of young and vigorous cells to take up the work of the older cells as the latter become less efficient and finally die.

The roots of monocotyledons.—Monocotyledons do not possess cambium, and are therefore incapable of secondary thickening. As they increase in size they have, nevertheless, the same need to increase the supply of soil-water, as well as the machinery for distributing both soil-water and food. The need is met—not by the great development and branching of the radicle of the seedling to form a tap-root system, as is usual with dicotyledons—but by the growth of a large number of *separate* roots endogenously from the base of the stem (Figs. 26 to 29, 109 and 114).

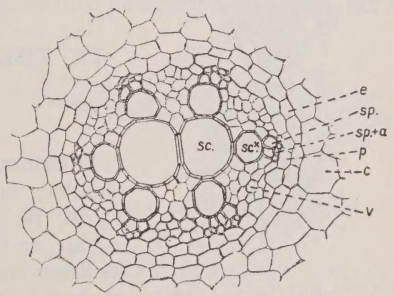


FIG. 87.—Central region of the root of a monocotyledon (Onion) in transverse section. Note the absence of cambium. *c*, cortex; *e*, endodermis; *p*, pericycle; *a*, annular, *sp*, spiral tracheids of xylem; *sc*, *sc*, scalariform vessels of xylem; *v*, phloem. (× 120.) (After Strasburger.)

Adventitious roots.—Such roots, which do not arise in acropetal succession from a tap root or its branches, but grow irregularly from some other part, are said to be adventitious. Adventitious roots occur not only in all monocotyledons; they are also formed in many dicotyledons, either (1) because for some reason the cambium is suppressed or inactive, or (2) because the tap-root system is inadequate. An interesting instance of the first condition is found in buttercup roots (Fig. 88), where the central cylinder is enclosed in a hard endodermis (Fig. 82) which is perhaps too unyielding to allow room for the development of new tissue inside it. The second case, where the original tap-root

system of a dicotyledon is supplemented or superseded by adventitious roots springing later from the stem, is found not only when the tap root has been damaged, but also normally in dicotyledons which have prostrate stems or branches, or increase in numbers by the separation of a part of the original plant (p. 194). The ivy (p. 190) uses adventitious roots for climbing. The roots of many plants become much swollen by stored food (Chap. XII.).

FIG. 88.—A Buttercup, a dicotyledon having adventitious roots.

17. THE MAIN FUNCTIONS OF ROOTS.

PRACTICAL.

1. Osmotic pressure.—Obtain a pig's bladder, half fill it with treacle or syrup, tie up the neck without including air, and hang up the bladder so that its lower end dips into water. Keep the bladder moist. Notice that the quantity of liquid in the bladder increases until it becomes full and tightly stretched, showing that it has absorbed water through its walls.

2. Root pressure.—On a damp warm spring day cut off the stem of a vigorous sunflower, bean, or other plant just above the ground, and notice the free escape of liquid from the top of the stump. Attach a long glass tube of the same diameter as the stem by means of indiarubber tubing, and support the tube in a vertical position by tying it to a stick thrust into the ground or clamping it to a retort stand. Notice the rise of liquid in the tube.

The work of the roots.—We have seen (p. 115) that for the adequate nourishment of the plant its leaves must be provided, not only with the carbon dioxide which they obtain from the air, but also with an abundance of water containing certain mineral salts in solution. This water, with its dissolved salts, can, in the case of land plants, be obtained only from the soil.

Hence the need for organs able to penetrate the soil and to find, and absorb, this soil-water and pass it on to the leaves. For this work the root system is beautifully adapted in all respects. Roots also find in the soil, and absorb, a great deal of the oxygen the plant needs for respiration. Finally, the use of the roots to anchor the whole plant firmly in position must not be lost sight of, since a certain security of tenure, after the plant has adjusted itself to its environment, is obviously necessary for the successful completion of its life-work.

The absorption of soil water.—The soil water is absorbed by the long cells called root-hairs which grow out from the surface of the part just behind the elongating region of each root and rootlet; that is, from the part which has just finished elongating. Obviously the hairs would be useless both on the younger (growing) part of the root (because they would be torn off by the movement of this part through the soil), and on the older (thickening) part (because this soon becomes covered with waterproof cork). The root hairs insinuate themselves between the particles of the soil and come into very close contact with the films of moisture clothing the particles. Thus the cell sap inside a hair is only separated from the soil-water by a very fine cell wall and a thin layer of protoplasm lining the cell wall. The cell sap, moreover, is "stronger" than the soil-water. The consequence is (p. 93) that the soil-water makes its way by **osmosis** through the cell membrane into the cell sap of the hair (carrying with it more or less * of the salts it holds in solution), somewhat as water makes its way from outside through the wall of a bladder containing a sugar solution (Expt. 1, p. 134). The cell sap of the hair, however, is diluted by the entrance of the soil-water, and is thereby made weaker than the sap contained in the neighbouring cells of the

FIG. 89.—Tip of a root-hair with adhering particles of soil. (× 240.) (After Noll.)

* The amount of each salt absorbed depends on the difference of its concentration inside and outside the cell, and on the permeability of the osmotic membrane with respect to it.

cortex with which the hair is in contact. The result is that a flow of water takes place from the hair in question to these neighbouring cells, and similarly in turn from these to the inner cells in contact with them. The diffusion is thus continuous from the hairs to the inner cortical cells abutting on the central cylinder. If, on the other hand, the cell sap were "weaker" than the soil-water, the root hairs would not absorb the water (p. 94); on the contrary, water would be withdrawn from the hairs and the neighbouring cells into the soil.

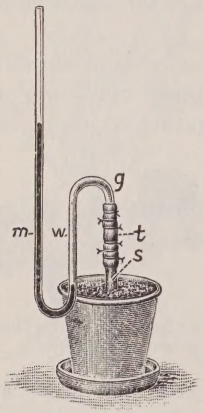


FIG. 90.—Vigorous exudation of water, as the result of root pressure, from a cut stem of Dahlia. The smoothly cut stem *s* is joined to the glass tube *g* by the rubber tubing *t*. The water *w*, absorbed by the roots from the soil, is pumped out of the vessels of the stem with a force sufficient to overcome the resistance of the column of mercury *m*. (After Strasburger.)

Root pressure.—Such diffusion from a weak to a strong solution may account for the flow of solutions from soil to root hairs and from root hairs, cell by cell, to the inner cortex of the root, but it cannot explain the so-called "bleeding" which takes place from the stumps of stems of vigorous plants cut across in the spring. The force with which the roots are obviously pumping water up the stem in such cases is astonishingly large. It may generally be measured by fixing a glass tube of the same diameter to the stem by rubber tubing and observing the height to which water rises in the tube (Fig. 90). In some cases the water rises to such a height that it is more convenient to measure the pressure by using a gauge of mercury (the density of which is 13·6 times that of water) in the manner shown in Fig. 90.

The root of a bleeding vine may often be proved in this way to be pumping water up the stem with a force sufficient to raise a column of mercury to a much greater height than 30 inches: in other words, the root pressure considerably exceeds the ordinary pressure of the atmosphere—some 15 lbs. per square inch—on the stem surface experimented with. The root pressure of most plants, however, is much less than this, and varies widely according to circumstances. The precise way in which the

living cells of the inner cortex " pump " water into the dead wooden vessels of the xylem is still a mystery.

Roots do not absorb soil-water vigorously unless they are healthy, and they cannot remain healthy unless they are supplied with oxygen for respiration. Root pressure, therefore, is found to fall off if the air is driven out of the soil by over-watering; in such cases the roots are being suffocated. Temperature also affects the activity of the roots: a plant growing in a pot kept surrounded by ice soon shows by the limpness of its leaves that absorption is not keeping pace with transpiration, though the soil may be quite moist.

The transpiration current.—The soil-water absorbed by the roots makes its way along the woody vessels of the xylem of roots and stem to the leaves. There, most of it is evaporated in the process of transpiration (p. 79), the dissolved mineral salts being left behind and utilised in the manufacture of food (p. 115). It seems that the main use of this current (called the transpiration current) is to provide the plant with the dissolved salts which it conveys. It is plain that in the process of transpiration the cell sap of the mesophyll cells must be concentrated by evaporation of their water. This will cause an osmotic flow of water from neighbouring cells, which in turn will be supplied from the water in the continuous system of xylem vessels in leaf-veins, leaf-stalk, stem and root.

Thus the water of the transpiration current is, as it were, being " pulled " up by transpiration from above, and " pushed " up by root pressure from below, at the same time. If root pressure does not keep pace with transpiration, as often happens in hot dry weather, some of the very slender columns of water in the xylem vessels are subjected to a pull only. It is found, however, that the tensile strength of such fine threads of liquid is very great. Indeed, a column of fresh sap has been known to withstand a tension equal to more than 200 atmospheres without rupture.* Although all these factors—root pressure, transpiration, and the tensile strength of fine liquid columns—play an important part in maintaining the transpiration current, the process is not yet fully explained to the satisfaction of all botanists.

* Prof. H. H. Dixon.

EXERCISES VIII.

1. Describe the root system of some perennial herbaceous plant : name the plant.

2. Describe carefully the *external features* of the root of a plant such as the broad bean. State clearly the parts of the root which are concerned with the following duties : (*a*) growth in length ; (*b*) absorption from the soil ; (*c*) protection from injury. (J.M.B. Sch. Cert. and Matric.)

3. Explain carefully by what means the plant absorbs water from the soil. Why is it important for the performance of this function that the root should continue its growth ? (O.S.)

4. Explain how the structure of a root enables it (*a*) to force its way through hard soil, (*b*) to absorb moisture from the soil. (C.S.)

5. What are root hairs, where are they found, and what is their function ? (J.M.B. Hr. Sch. Cert.)

6. Show how the structure of a young root of a dicotyledon is related to the functions it performs. (C.H.L.)

7. Describe the external features and mode of growth of the young root of a dicotyledonous plant, explaining their importance in relation to its situation and functions. Without entering into minute details, say what changes occur in it as it becomes older. (J.M.B. Matric.)

8. Give an account of the growth in thickness of the root of a dicotyledon. What do you know of the origin and development of the lateral roots ? (J.M.B. Hr. Sch. Cert.)

9. Write an illustrated account of the process of secondary thickening in the root of a dicotyledon.

10. Describe two simple experiments, the first to demonstrate the physical phenomenon known as osmosis, the second to show respiration in a plant. (J.M.B. Matric.)

11. It is stated that the " sap " of trees rises in spring. Discuss this statement, and give experimental evidence in support. (Prel. Cert.)

12. Describe experiments that you have set up to show : (1) how water enters the root, (2) the force with which it enters. (J.M.B. Jun. Cert.)

13. What is meant by root pressure, and how would you demonstrate it experimentally ? In what external conditions is the root system of a plant specially active ? (L.M.)

14. What effect has cold weather on (*a*) absorption of water by roots, (*b*) transpiration ?

How do you account for the thickness and leathery texture of evergreen leaves ? (J.M.B. Matric.)

15. Give an account, including some experimental evidence, of the means by which plants are able to absorb mineral solutions from the soil.

Discuss the statement : " It is possible to starve a plant by overfeeding it." (Cert.)

CHAPTER IX.

THE GENERAL STRUCTURE AND FUNCTIONS OF STEMS.

18. THE STEM AND ITS BRANCHES.

PRACTICAL.

1. Leaves, buds and branches.—Make diagrams of the growth and branching of the stems of various common flowering plants, noting (*a*) that each branch begins as a bud in the axil of a leaf; (*b*) that a stem or a branch grows in length by the development of the bud at its tip, and is incapable of further *direct* growth if this "terminal bud" is lost. Study the behaviour of the terminal bud of branches of willow, elm, lime and lilac in summer and autumn, and say how subsequent growth differs from that of sycamore, privet, elder, etc. Make diagrams of the branching of marsh marigold, buttercup, stitchwort, campion, strawberry, etc., indicating the original stem by *a*, branches of *a* by *b*, branches of *b* by *c*, and so on. Try to find out why so many horse-chestnut twigs are forked.

2. The path of the water current to the leaves.—Cut off leafy stems of various herbaceous plants (*e.g.* sunflower, deadnettle, bean, buttercup, maize, tulip, asparagus) and expose to light with their cut ends dipping in water coloured by red ink. After some hours cut open the stems, and notice the coloured strands. Cut transverse sections and draw diagrams showing the position of these strands as seen with a lens, and also of any other strands which are not coloured red. Also cut thin cross sections with a razor, mount them in water, and identify the tissues (see Figs. 93 to 95). Contrast the arrangement of the conducting strands (vascular bundles) in the dicotyledons and monocotyledons. Make longitudinal sections through the insertions of leaves, and try to explain any marked difference in transverse sections of

the dicotyledon and monocotyledon stems, *e.g.* sunflower and maize or tulip. Take other pieces of stem and boil them in water until the internal tissue is soft. Then scrape away all the soft material until the strands can be seen well.

The work of the stem.—We have learnt that for the making of all plant food it is essential that certain green parts (which in most higher plants are leaves) shall be exposed to light. The food-making parts must, in other words, be above ground. We know also that the materials, from which the food is made, are obtained partly from the air and partly from the soil. It is thus plain that there is need for machinery (*a*) for transmitting soil-water to the leaves from the organs (roots) which absorb it, and (*b*) for transmitting food from the leaves to the roots to nourish the latter. These then are **the fundamental uses of the stem**—

(1) to expose the leaves to light, and

(2) to carry solutions from root to leaves and from leaves to root.

By the growth of the stem in length and, in many cases, by the formation of branches—that is, *lateral duplicates* of itself—which may themselves branch extensively, the leaves are borne in such positions that they are suitably placed to receive the necessary light supply. The stem and its branches also expose certain flowers and fruits in positions favourable for pollination or seed dispersion by the wind (pp. 342 and 361), and display conspicuously other flowers and fruits which depend on insects and birds respectively for the same services (pp. 343 and 359). We shall see later that stems are often useful to plants in other ways as well.

The rate of growth of a stem.—The increase in length which a stem undergoes in a certain time may be conveniently measured by a simple instrument called a *growth lever*. This consists of a light rod pivoted much nearer one end than the other. The end of the short arm is attached by a thread to the tip of the stem of a growing plant (protected by being wrapped in cotton wool) while the long arm moves over a graduated arc. The short arm is weighted (*e.g.* by lead foil) until the thread is only just kept

tight by the upward pull. The end of the short arm of the lever rises, and that of the long arm falls, as the stem grows in length. If the long arm is, say, ten times the length of the short arm, its end moves through a distance equal to ten times the increase in length of the stem. In other words, if the end of the long arm falls one inch in a certain time we know that the stem has grown one-tenth of an inch in that time. Self-recording instruments on the same principle, known as *auxanometers*, are also to be obtained. They are provided with a device by which the end of the long arm traces a line on a scale moved by clockwork.

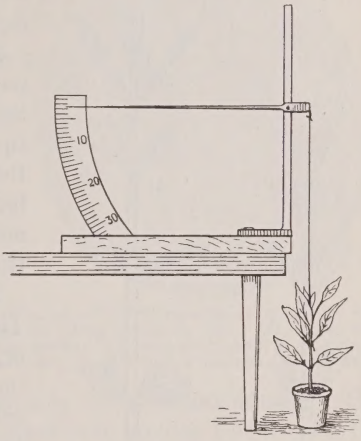


FIG. 91.—Simple form of growth lever.

By means of a growth lever or auxanometer we can compare the rate of growth of a stem under different conditions. In this way it has been found, for example, that the stem grows more rapidly in the dark than in the light. It grows most quickly a little after midnight, and most slowly a little after midday.

The region of most rapid growth.—In studying the development of **seedlings** from seeds (p. 32), we found considerable differences in the rate of growth of the two regions (plumule and hypocotyl) of the young stem. In the pea, broad bean, oak, etc., the hypocotyl remains small, and the growth of the stem is restricted to the plumule. On the other hand, in sycamore, vegetable marrow, kidney bean, castor oil, etc., the elongation of the stem is at first due entirely to the growth of the hypocotyl. By marking the elongating part (plumule or hypocotyl) with Indian ink at equal intervals, and observing how much the various marks become separated during subsequent growth, it is easy to compare the rates at which different regions of the stem are growing longer—information which a growth lever or

auxanometer does not supply, since it only measures the *total* elongation. Such experiments show that while growth takes place over the greater part of the plumule or hypocotyl, it is least rapid near the end, and most rapid near the middle.

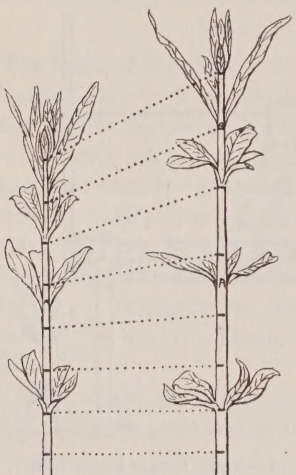


FIG. 92.—On the left, a growing shoot marked at equal intervals with Indian ink. On the right, the same shoot a day later. (After Errara.)

After the seedling stage has been passed, the growth in length of the stem takes place chiefly in the tip-region, though elongation of the younger internodes continues for some time (Fig. 92). The nodes take no share in increasing the length of the stem.

How the stem grows longer.—The "growing point" of a stem or branch is the region at, and immediately behind, the tip. The cells of this region divide rapidly. Distended and fed by the rich food brought to them from the active foliage leaves, or from some store of nourishment laid up previously, the new cells thus formed increase in size, their stretched walls being saved from undue thinness by the deposition of fresh cellulose on their insides. The new cells behave differently according to their position. Those which are farthest from the tip gradually take on the forms and activities of the neighbouring older cells; those nearest the tip continue to divide rapidly. In this way a repeated increase of material takes place in the direction of the length of the stem; in other words, the stem grows longer. As the end moves onward, the young leaves clustered round it are successively left behind, while new leaves arise in their turn nearer the tip. For some time the internodes grow longer by the division and increase in size of the cells of which they consist, and in this manner the leaves are carried further and further apart. Loss, or temporary failure, of the power of normal

internodal extension accounts for the "rosette" habit seen in many herbaceous plants (pp. 199 and 206), and for the formation of "dwarf shoots" in trees (p. 151).

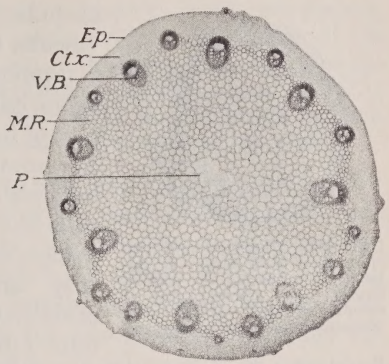


FIG. 93.—Photomicrograph of transverse section of young Buttercup stem. *Ep.*, epidermis; *Ctx.*, cortex; *V.B.*, vascular bundle; *M.R.*, primary medullary rays; *P.*, pith or medulla. (T.D.T. Hall.)

The general structure of stems.—The essential features in the architecture of stems are best studied in unthickened herbaceous plants. The stem of such a plant consists of (1) an external skin or **epidermis**, like that of the leaf; (2) a band of tissue called the **cortex**, consisting mainly of parenchymatous cells (p. 96) with abundant intercellular spaces containing air; (3) a **central cylinder**. The main regions of the stem are thus very similar to those of the root in position (p. 128). The cortex is, however, much narrower in proportion, and the central cylinder much wider, in the stem than in the root.

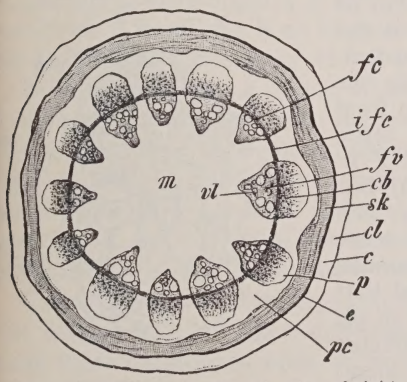


FIG. 94.—Transverse section of a stem of *Aristolochia Sipho*, 5 mm. in thickness. *m*, medulla; *fv*, vascular bundle; *vl*, xylem; *eb*, phloem; *fe*, fascicular cambium; *ifc*, interfascicular cambium; *p*, phloem parenchyma; *pc*, pericycle; *sk*, ring of sclerenchyma; *e*, endodermis; *c*, cortex; *cl*, collenchyma in cortex. (×9.) (After Strasburger.)

The central cylinder.—The conducting apparatus of the stem consists of a variable number of long strands called *vascular bundles*, which run longitudinally through the central cylinder. In young **dicotyledon stems** in cross section these show to the naked eye as a single ring of dots near the outside of the central cylinder (Figs. 93 and 94). At the nodes, the vascular bundles are connected with each other

(by cross bridges), and also with the veins or vascular bundles of the leaves. The middle of the stem is called the *pith* or medulla; the tissue separating each vascular bundle from the next is called a primary *medullary ray*; while the region lying between the cortex and the ring of bundles is called the *pericycle*. The primary medullary rays thus reach from pith to pericycle. In **monocotyledon stems** the bundles do not always form a single ring, but are often more irregularly arranged (Fig. 95), so that medullary rays are not obvious; the term pith is also less applicable than in dicotyledons, since some of the bundles may approach the centre of the stem in part of their course.

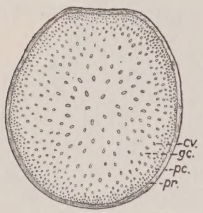


FIG. 95.—Transverse section of internode of Maize stem. *pr*, cortex; *pc*, pericycle; *cv*, vascular bundle; *gc*, ground tissue of central cylinder. (×1.) (After Schenck.) Compare with Fig. 109.

The vascular bundles.—Each bundle consists of (*a*) **xylem** on the side adjoining the pith, (*b*) **phloem** or bast on the side adjoining the pericycle. Xylem and phloem are thus *collateral* (that is, they lie on the same radial line) in the stem, while—as will be remembered—they are *alternate* in the young root. The transition from one arrangement to the other takes place in the hypocotyl. In most dicotyledons (Fig. 96), but not in monocotyledons, a thin sheet of **cambium** lies between the xylem and phloem of each bundle. It will be easily understood that where the bundles bend out to the leaves, the xylem (which is directed towards the centre of the stem) comes to face the *upper* surface of the leaf, and conversely, that the phloem is on the *lower* side of each leaf vein.

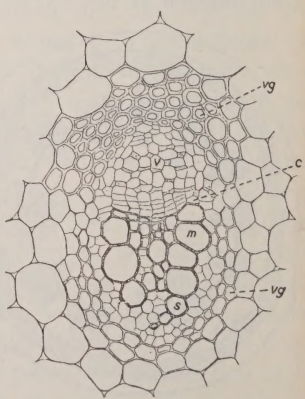


FIG. 96.—Transverse section of vascular bundle of stem of Creeping Buttercup. *s*, *m*, vessels of xylem; *c*, cambium; *v*, phloem; *vg*, sheath of sclerenchyma. (×90.) (After Strasburger.)

In such a stem the vascular bundles thus form branching strands of conducting pipes, packed—as it were—in a softer succulent "ground tissue" of parenchymatous cells, the

whole being bound together by a thin but tough skin or epidermis.

The plant is thus provided with a complete circulatory system. The soil-water travels up the continuous wooden vessels of the xylem from root to stem and out to the leaves; the leaves make foods from this solution and the carbon dioxide which enters by the stomata; and these foods are believed to be distributed through the sieve tubes of the bast * to all active parts of the plant.

A herbaceous stem such as has been described is plainly capable to a certain extent of performing the usual **functions of the leaf**; for the outer cells of the cortex, being exposed to light through the transparent epidermis (which is like that of the leaf (p. 103)), develop chlorophyll in their plastids, and—being supplied with the carbon dioxide necessary for photosynthesis through the stomata of the epidermis—behave in all respects as mesophyll cells. Some transpiration also takes place through the stomata of the stem epidermis.

The branching of the stem.—The power of extensive branching, which so many stems possess, is of very great importance, for it permits a corresponding extension of the leaf system and its activities. Branching is no haphazard process, but is regulated by habits which closely-related plants have in common.

In flowering plants a branch almost invariably originates as a bud **in the axil of a leaf**; thus the manner of branching depends in the first place upon the arrangement of the leaves (phyllotaxis, p. 46). It follows that even in cases where the branch is so large as, or larger than, the stem from which it springs, the position of the leaf (or of the scar which the leaf leaves when shed) indicates which is the main stem and which is the branch.

Careful longitudinal sections through the tip of a stem—where the earliest stages of leaves and branches are to be found—show that these outgrowths arise as mere elevations of the *external* tissues—the epidermis and the outer cortex—and have for some time no direct connection with the central cylinder or the vascular bundles (Fig. 31). They are therefore said to be **exogenous**. In this respect they differ from the endogenous branches of the root (p. 132).

* See p. 156.

Monopodium and sympodium.—A stem, or a branch of a stem, which from the first has elongated in the manner described on p. 144, is plainly a continuous structure, since it has been formed by the development of one and the same bud. Such a stem is called a **monopodium** (Fig. 97, A). It is evident that a stem or branch can increase *directly* in length so long, but only so long, as its terminal bud remains intact.

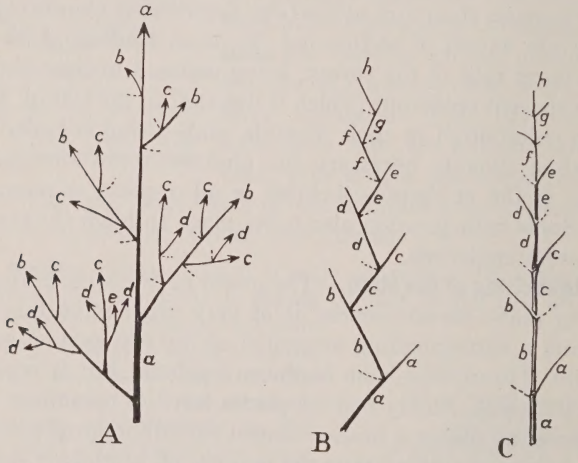


FIG. 97.—Diagrams of methods of branching in stems of flowering plants. *A*, Monopodial; *B* and *C*, Sympodial. *b* is a branch of the original axis *a*; *c* is a branch of *b*, *d* of *c*, etc. Leaves are shown by dotted lines. For simplicity, alternate branching is illustrated.

Should the terminal bud be destroyed, or wither, or its apex be modified to form a flower or a group of flowers, no further extension of the axis bearing it is possible. In such cases it is usual for the axillary bud next behind to grow out and form a new "leader." This may, and often does, grow in the same direction as the stunted original axis, but the new leader is nevertheless morphologically a branch of the old one. The growth of the new leader in its turn may presently come to an end by the loss of its terminal bud, to be succeeded by one of its own branches. In this way a succession of branches may assume the *appearance* of a continuous axis. Such a succession of branches is called a **sympodium** (Fig 97, B, C). Sympodial

branching occurs in most creeping stems (p. 195), and also in most British trees (*e.g.* lime, elm, birch, hazel, hornbeam, willow). In these trees the terminal bud of each branch usually withers

FIG. 98.—Upper part of a branch of White Willow in September. *t.b.*, scar of lost terminal bud; *a.b.*1, last axillary bud, which will form the new leader next spring. ($\times \frac{1}{2}$.)

and falls away in summer. The true axillary nature of the *apparent* terminal bud which succeeds it may be recognised by the leaf or leaf-scar below it (Fig. 98).

In plants with opposite leaves (and consequently opposite axillary buds), if the terminal bud dies or becomes a flower or flowers, it is usual for the *pair* of buds next below to grow out, and the stem therefore "forks" to form what is called a *dichasium*. The lilac and the mistletoe, as well as the flowering twigs of horse chestnut (Fig. 99), are excellent examples of this habit.

It is clear that dichasial branching will *tend* to extend the growth of the plant at the sides rather than upwards; and that the monopodial method will result usually in a spire-like habit of growth (Fig. 348). Such differences are more marked in

herbaceous plants than among trees. The various methods of branching become most interesting and significant, however, in flower-bearing shoots, as will be seen in Chapter XVI. (p. 309).

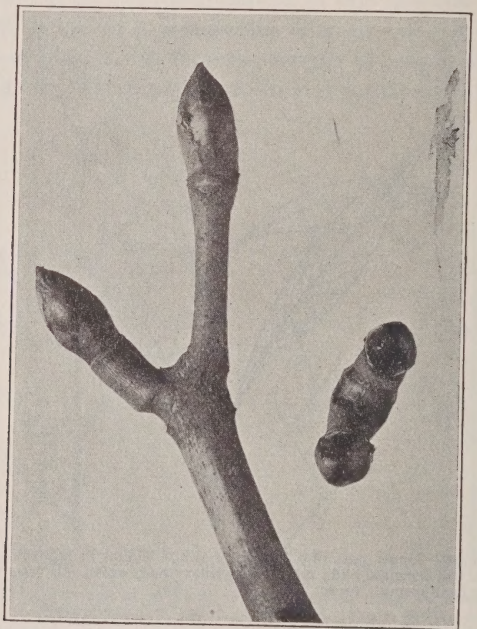


Photo. Henry Irving.

FIG. 99.—Forking of Horse Chestnut twig as a result of flowering. (Compare with Fig. 316.) On the right, the saddle-shaped scar left by the fallen flower-shoot, as seen from above.

Limitations of the power of branching.—It is obvious that unrestricted branching, even in a solitary plant, would soon lead to the production of many leaves unable to make food because they would be overshadowed by others. The result would be the starvation and death of the branches bearing such leaves—a fate which normally overtakes the lower branches of trees in a plantation, and of other closely grown plants as they become shaded by leaves of later branches at a higher level. The consequence is that the trunk grows tall and straight. As a matter of fact, wasteful branching is uncommon, since it is only rarely that all the buds formed by a plant grow out to form branches.

Local lack of sufficient food to supply the new material required is probably the chief reason of the failure of buds to develop. Many buds, especially axillary buds, therefore remain dormant or latent unless the loss of active "leaders" puts more food at their disposal and enables them to grow into branches, as when the clipping of a hedge causes it to grow more thickly. Otherwise, *dormant buds* may merely keep pace with the thickening of the stem so as to remain at the surface, and perhaps develop after many years. This is the explanation of the growth of small leafy twigs from the bottom of tree trunks, or of "stool shoots" from the stumps of felled trees. On many trees, the terminal buds of certain short branches unfold every spring, but only grow perhaps a fraction of an inch each season. They are well seen in beech (Fig. 100), and are called *dwarf shoots*. Other kinds of dwarf shoots are the "fruiting spurs" of apple, etc., the thorns of hawthorn, and the bifoliar spurs of pine (p. 460).

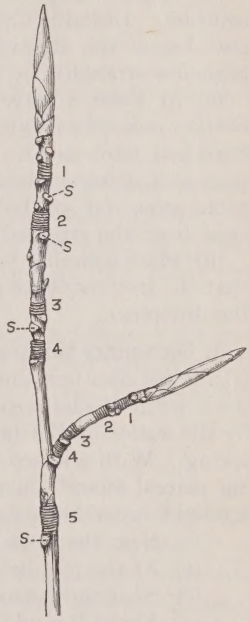


Fig. 100.—Dwarf shoots of Beech in winter. *s*, leaf scars; 1, 2, 3, 4, 5, girdle scars showing position of terminal bud 1, 2, 3, 4 and 5 years ago. (Natural size.)

19. WOODY STEMS.

Practical.

1. The path of the transpiration current.—Put a leafy twig of elder into water coloured by red ink, and expose to sunlight for an hour or two. Cut open the twig and observe that the bark and the soft tissues between it and the wood are not coloured. The *wood* is stained red. The pith is not coloured. Which part of the stem transmits water to the leaves? Compare with Expt. 2, p. 141.

2. The path of the leaf-made food.—(*a*) In spring twist a wire tightly round a twig (of elder or other freely branching tree) below

the leaves, and observe if this branch differs in behaviour from the others during the summer. After the leaves have fallen, take off the ligature, split the twig down the middle and apply iodine solution. Describe and explain any differences to be seen above and below the ligatured part. Search woods and hedges for branches strangled by honeysuckle.

(*b*) (i) Take a leafy branch of willow or rose, and near the bottom remove a ring of the bark and the soft tissues lying between bark and hard wood. Put the twig in water, so that the ringed part and a few inches above it shall be immersed. Notice that roots grow out at the upper edge of the stripped part. If any arise from the stripped part they are fewer and shorter.

(ii) Place a similar twig, cut clean through, in water, and notice that the new roots are produced at the end. Suggest a reason for the difference.

3. Secondary thickening of stems.—(i) In summer take a twig (*e.g.* horse chestnut, lime) of three or four years' growth. Identify the growth of each year by means of the rings of girdle scars left by the scales of the terminal bud when it resumed growth each spring. With a sharp knife cut transverse sections at the following places, mount them in water and examine them, held up to the light, with a lens ; or use a low power of the microscope :

(*a*) Near the apex ;
(*b*) At the middle of the current year's growth ;
(*c*) Near the bottom of the current year's growth ;
(*d*) About the middle of last year's growth ;
(*e*) ,, ,, ,, the previous year's growth.

Draw a section from each region. In (*a*) the twig is covered by a green skin (*epidermis*). In the middle is the soft *pith*. Between the two is a ring of separate strands (*vascular bundles*). In (*b*) and (*c*) the strands have joined up, and a distinct, though thin, layer of *wood* surrounds the pith. Next outside the wood comes a very thin layer, the *cambium*, outside the cambium is the dark green band of *bast* or *phloem*, outside the phloem a ring of strengthening fibres (brownish dots in cross section, not seen in lime), and between the fibres and the *bark* is the *cortex*. On the bark notice the *lenticels*, like pinpricks. Section (*d*) has two layers of wood. Section (*e*) has three layers of wood. Treat each section with iodine solution, and notice that radial lines through the wood (*medullary rays*) become darkly stained. Why ? What other parts of the stem contain starch ?

(ii) Split each year's growth longitudinally, and in each piece

observe that the tissues named above form coaxial cylinders. See how the vascular bundles are continuous with those of the leaves. Cut lengthwise through the junction with any side twigs, and notice that corresponding tissues are continuous.

Branching and secondary thickening.—The fact that branching is conditioned by the food-supply (p. 151) has far-reaching effects on the manner of growth of plants. For since the increased branching is impossible without both increased food-making and increased food-distribution, and since increased food-making in its turn necessitates increased supplies of soil-water, it is plain that branching must be very limited unless the plant can provide more conducting tissues.

Many dicotyledonous herbs and all dicotyledonous trees and shrubs, as well as pines, firs, larches, and related trees, provide themselves—in stem as well as in root—with the necessary extra conducting tissues (xylem and phloem) by the process of secondary thickening.

Secondary thickening, as we have already learnt in the case of the root, **depends upon the activity of cambium.** Monocotyledons, however, have no cambium, and are therefore incapable of secondary thickening. We may associate this fact (*a*) with their possessing only adventitious roots (p. 133), and (*b*) with the small number of leaf-bearing branches * formed by monocotyledons. When such branches are formed, it is usually close to the ground, and each branch puts out adventitious roots which render it independent. Indeed, it often becomes detached from the main stem and grows as a separate individual. This is known as vegetative propagation (Chapter XII.).

Many herbaceous dicotyledons live under similar restrictions and produce only weak and short-lived aerial shoots, since their cambium is greatly reduced and may even be lost entirely. Such dicotyledons, like monocotyledons, either branch very little, or put out adventitious roots whenever the branches form foliage leaves (*e.g.* strawberry, buttercup). Vegetative propagation is common among such plants also.

* Flower-bearing branches are in a different category since flowers depend upon food *previously* made and stored by the plant.

Secondary thickening of stems.—In most dicotyledons, however, cambium is present and active, and the branching of the stem, like that of the root, is accompanied by the thickening of the axes already formed, the additional xylem and phloem necessary being thus provided. In a young part of a stem or stem-branch, cambium occurs only in the vascular bundles, between xylem and phloem. In each bundle it consists of a strip of narrow cells with very thin walls. Presently the adjoining cells in the medullary rays become modified to resemble in all respects the cambium in the bundle, so that the cambium is soon a continuous cylindrical sheet of tissue reaching quite round the stem (Fig. 94). Its cells divide freely; the resulting new cells enlarge; those on the inner (pith) side of the group change into xylem; those on the outer (pericycle) side change into phloem; while the cells between remain as cambium and retain the power of unlimited division. The result is not only that new (secondary) xylem is added to the outer border of the original (primary) xylem of each bundle, and secondary phloem to the inner border of its primary phloem, but also that xylem and phloem are laid down in the primary medullary rays.

It is to be noted also that since the cell walls of the new xylem are for the most part converted into wood, this new tissue is very hard and resistant; and as it accumulates it pushes all outer tissues—cambium, phloem, pericycle, cortex and epidermis—further from the centre of the stem. From time to time small patches of the cambium cease to form xylem and phloem, but produce parenchyma instead, with the result that horizontal radial spokes of parenchyma, called *secondary* **medullary rays,** are left embedded in the secondary xylem and phloem (Figs. 101 and 102). The medullary rays conduct water and food materials *across* the stem, and also are storage places for starch, etc., in winter.

Secondary thickening is seen in the greatest perfection in trees. The formation of new wood (xylem) and bast (phloem) takes place vigorously during the spring and summer, at the expense of the abundant food supplied to the cambium. As autumn comes, the activity of the tree slows down, less water is sent up by the roots, and the new wood-vessels are of correspondingly smaller bore (Fig. 101). In winter the process stops altogether; but with the warmth of spring the formation of new wood, with wide vessels to conduct the large supplies of water needed, is resumed.

The difference in texture between the autumn wood of one year and the spring wood of the following year is quite visible to the naked eye, and gives rise to a series of layers called **annual rings**, each of which normally represents a year's growth.* Thus, a cross cut through the four-year-old part of a branch (Figs. 101 and 102) shows four layers of wood, one of which was

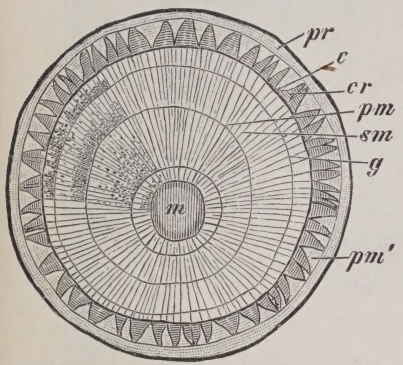


FIG. 101.—Transverse section of stem of Lime in its fourth year. *pr*, cortex; *c*, cambium; *cr*, bast; *g*, limit of third year's wood; *m*, medulla (pith); *pm*, primary medullary ray; *pm'*, expanded extremity of *pm*; *sm*, secondary medullary ray. (After Schenck.)

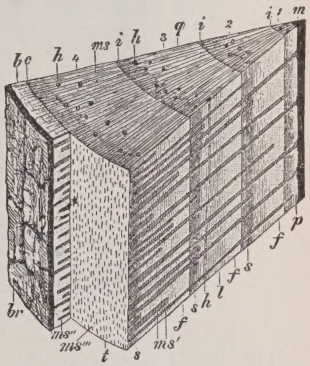


FIG. 102.—Portion of a four-year old stem of the Pine, cut in winter. 1, 2, 3, 4, the four successive annual rings of the wood; *b*, bast; *br*, bark; *c*, cambium; *f*, spring wood; *i*, junction of wood of successive years; *m*, pith; *ms*, medullary rays; *s*, autumn wood. (× 4.) (After Schenck.)

formed each year. The length formed last year has two layers of wood (if we look in summer), and the current year's growth has one layer, all of which has been formed since last winter.

The pith of a tree is usually obliterated.

The function of wood.—As a rule, only the later-formed rings of wood are actually used for **the transmission of water** from the roots of a tree to its leaves, as may be seen by putting the cut end of a fairly large leafy branch into water coloured by red ink. In such an experiment the inner wood (called the **heart wood**) is stained only slightly, if at all, while the outer layers (called **sap wood**) become reddened by the

* Any interruption of growth, however caused (as when the leaves of trees are eaten by caterpillars in late spring) may cause the formation of two thin rings instead of one of normal thickness (see p. 178).

passage of the coloured water through them. All other tissues remain unstained. As a matter of fact, the vessels of the heart wood usually become blocked, and the wood itself hardens and darkens in colour as secondary thickening proceeds.

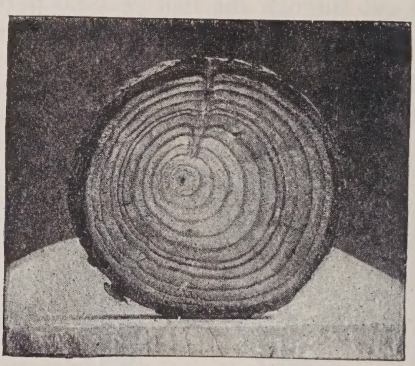


FIG. 103.—Cross-section of Larch stem, showing annual rings.

The heart wood of certain trees is very valuable as timber; the sap wood is not used as timber. The beautiful lines and patches called "silver grain," which may be seen in oak furniture, consist of the medullary rays of the heart wood, exposed in radial-longitudinal section.

A "knot" in timber consists of the base of a branch, surrounded by the wood of the trunk or limb on which it grew. A longitudinal saw-cut through the trunk may—according as it is radial or tangential—divide the branch longitudinally, obliquely, or almost transversely, the annual rings of the knot being shown by correspondingly parallel, oval, or nearly circular markings.

The function of bast.—It is not easy to prove directly that—as most botanists believe—the bast is the part of a plant which **distributes leaf-made food**; but indirect evidence in favour of this view is usually supposed to be obtained by removing a ring of all the tissues outside the wood from the lower part of a branch, say of willow or rose, and putting the branch into water. (These outer layers are very easily stripped off, especially in spring, because the cambium is soft and readily torn, and its cell contents are slippery.) When at length the cutting puts out roots, these

spring from the top of the ring. If any grow on the stripped part they are markedly smaller, and fewer. In an uninjured cutting, the bast of which is therefore continuous along its whole length, such roots spring from the cut end.

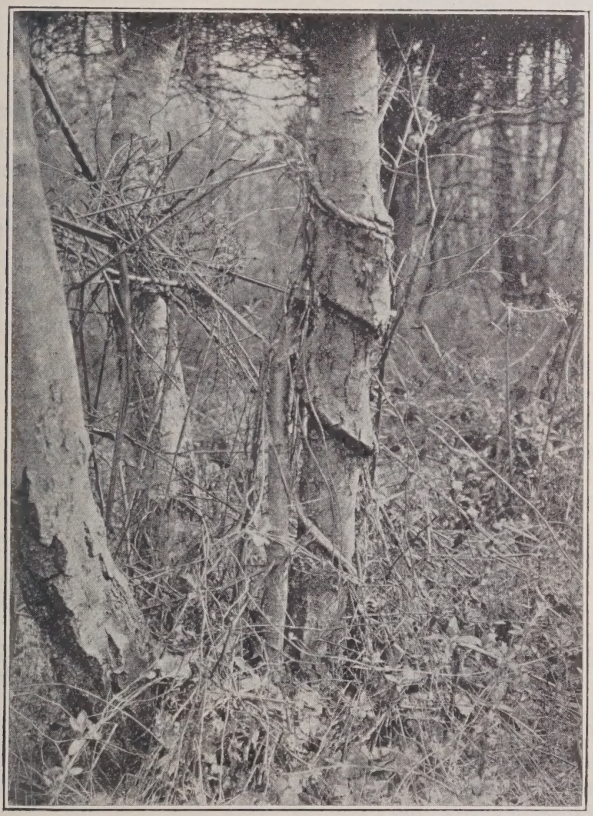


Photo. Henry Irving.

FIG. 104.—Honeysuckle growing on a Hazel stem.

The supply of leaf-made food can also be cut off by ligaturing a twig below the leaves, as by twisting a wire or cord tightly round it. This treatment crushes all the tissues outside the hard wood. In such a case growth of the twig usually ceases

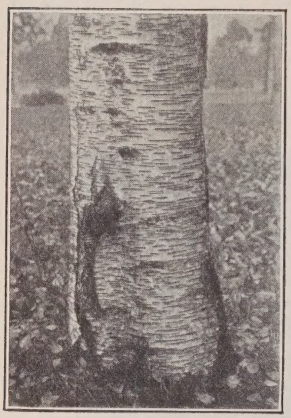


Photo. Henry Irving.

FIG. 105.—Trunk of Birch, with smooth bark.

below the strangled part, while the upper part, to which the leaf-made food is evidently now restricted, grows much more luxuriantly than before. This effect may be observed in woods or hedges, where a woody branch of honeysuckle has similarly strangled another tree by twining round it—witness the overhanging ledges where the surplus food has accumulated in the hazel stem of Fig. 104. It is put to practical use by gardeners, who sometimes produce unusually large fruits by ligaturing the lower parts of twigs on which fruits are ripening.

A different interpretation of the results of these experiments, however, is possible; for the ringing or ligaturing of stems in the way described above must destroy or strangle not only the bast and cambium, but also the still soft vessels of the outer layers of wood. There is no doubt that the normal upward current through the young wood (p. 155) is at times reversed by local changes in the tension of the sap, and Prof. H. H. Dixon has brought forward evidence indicating that—contrary to the generally accepted view—the leaf-made food is *usually* carried by such downward currents through the young wood, and not through the bast. (*British Association Reports*, 1922.)

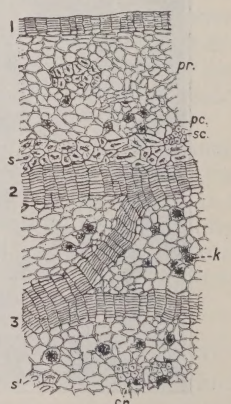


FIG. 106.—Transverse section of outer tissues of stem of Oak. 1, 2, 3, successively formed layers of cork; *pr*, cortex; *pc*, pericycle; *sc*, sclerenchyma fibres of pericycle; *cr*, fibres of bast. All external to the innermost layer of cork (3) is dead and discoloured, and has become transformed into bark. (× 112.) (After Schenck.)

Bark.—As in the root (p. 131), so in the stem, the addition of layer after layer of hard wood presently stretches the outer tissues to such an extent that tearing is inevitable. This would

expose the tree to considerable danger, were it not for the fact that, before tearing occurs, a sheet of special cells (called cork cambium) develops—sometimes in the pericycle (as in roots), sometimes in the epidermis (*e.g.* willow), or in the layer next below (*e.g.* elder), but usually in the cortex—and forms a layer of **cork** (Fig. 106). Now cork is elastic, air-tight and

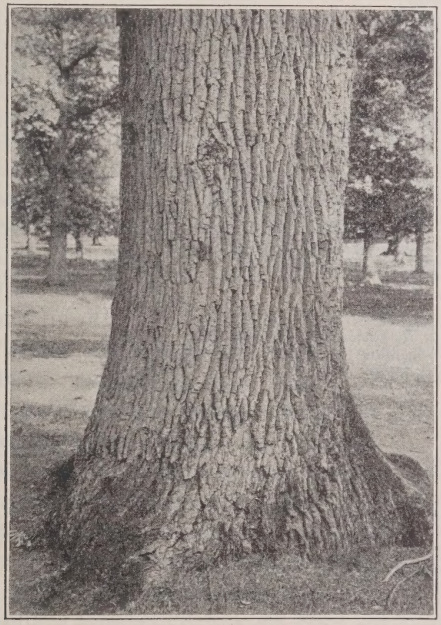


Photo. Henry Irving.

FIG. 107.—Trunk of Common Oak, with rugged bark.

waterproof, so that tearing taking place *outside* this layer does not involve any risk to the much more important tissues it encloses. The cork, however, naturally cuts off the supply of water and food from these outer layers, so that they die and dry up. The cork and the dead layers outside it together form what is called **bark**. In due course this first-formed cork naturally shares the same fate owing to the increasing bulk of the wood inside; but before it bursts, a new and deeper

layer of cork cambium has developed, and has formed a fresh layer of cork, which is replaced and discarded in its turn as the stem becomes still thicker. When the successive layers of cork are regular and parallel to each other, the bark is smooth (*e.g.* birch (Fig. 105), cherry, etc.); but when they are irregular and discontinuous (Fig. 106), the bark is rugged and breaks away in correspondingly irregular pieces (*e.g.* pine, common oak (Fig. 107), etc.).

Lenticels.—The formation of the corky bark naturally puts a stop to the photosynthesis, respiration and transpiration which the cortex, having access to the outer air by means of the stomata in the epidermis of the young stem (p. 147), at first carried on. Respiration and transpiration are, however, continued during the summer through pores (formed in the bark below the previous positions of the stomata), which put the living tissues of the stem into communication with the outside air. These pores are called **lenticels**. They are very obvious on the surface of twigs of elder, sycamore and many other trees, and somewhat resemble pin-pricks. During the summer the lenticels are loosely plugged with cork dust, but before winter they become closed by the formation of a new sheet of cork across their inner ends. The loss of water vapour through the lenticels, which in winter would be dangerous (p. 85), is in this manner prevented for the time being, a fact which gives trees a great advantage over herbaceous plants (p. 173). Lenticels are to be seen in bottle corks as dark-coloured channels, often containing cork dust.

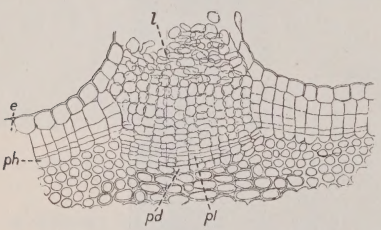


FIG. 108.—Transverse section of stem of Elder, through a lenticel. *e*, epidermis; *ph*, cork cambium; *l*, spongy cells filling the lenticel; *pd*, cork. (×45.) (After Strasburger.)

Growth of monocotyledon stems.—It has been said that monocotyledons—having no cambium—are incapable of secondary thickening; yet it is common knowledge that the stem of an old monocotyledon (*e.g.* a maize plant) is thicker than the stem which the same plant had when young. The explanation of this seeming anomaly is that the thick part of the full-grown

stem is the new upper part and has always been of its present thickness. The part which was thin when the stem was young is still thin, but has been pushed into the ground by the weight of the more recently formed tissues above it, or pulled down by contractile roots (p. 200). This condition is due to the fact that for a time the growing point of the terminal bud increases in vigour, and each new internode is *formed* thicker than those below it, until the apex attains the full thickness natural to the species. Up to this stage the stem has been like an inverted cone, but subsequent internodes are formed of equal width, and the rest of the stem is therefore cylindrical. Hence, while the thinnest portion of the dicotyledon stem consists of the latest-formed internodes, the thinnest part of the monocotyledon stem is to be found in the earliest-formed internodes.

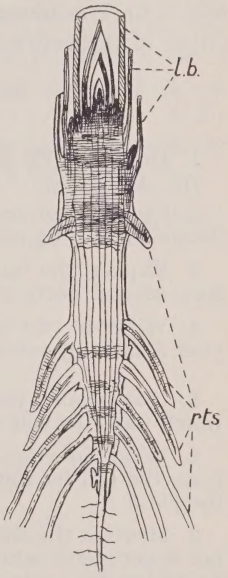


Fig. 109.—Diagram to show the habit of growth of a monocotyledon (Maize). *l.b.*, cylindrical leaf bases surrounding terminal bud; *rts.*, adventitious roots. (After Sachs.)

Stems and roots contrasted.—It will be convenient to summarise here the chief differences between stems and roots in flowering plants. Stems usually grow upwards and towards the light; roots usually grow downwards and away from the light. The tip of a stem, so long as it remains capable of growth, is clothed by young leaves, forming a bud; that of a root is covered by a root cap. The outside layer (epidermis) of the young stem is *protective* in function, being usually waterproof and air-tight (except through the stomata), and any hairs borne by it are also protective; the outside layer of the young root, with the hairs it bears, is *absorptive*; it should not be called epidermis. The stem bears leaves; roots very rarely bear leaves. The branches of the stem are exogenous, and in flowering plants arise as buds in the axils of leaves (flowers (p. 335) are modified stem-branches); branches of the root are endogenous, and form longitudinal rows on the main root. Many stems give off endogenous adventitious

roots; very few roots give off shoots. The central cylinder usually forms the greater part of the young stem, but only a narrow core in the young root. The primary xylem and primary phloem are collateral in the stem, but alternate in the root. Cork cambium originates in the pericycle of a root; but either in the pericycle, cortex or epidermis of stems.

EXERCISES IX.

1. Describe with the aid of drawings the specimen K. (K = hawthorn.) (C.J.)

2. Give a brief account of the work which the shoot of a herbaceous flowering plant performs.

3. Explain the main differences in structure between a woody stem several years old and a herbaceous stem. (C.S.)

4. What do you understand by conducting tissue? Illustrate your answer by reference to the structure of the stem and leaf. (C.J.)

5. How would you determine experimentally the path along which water travels in the shoot of a plant? (C.S.)

6. What do you know of the process of absorption of water from the soil by root hairs and the movement of water through the plant? (J.M.B. Hr. Sch. Cert.)

7. Mention the chief functions of the stems of plants. Describe *two* experiments which afford information as to the movement of liquid substances in stems. (O.S. Gen. Science I.)

8. Describe experiments which demonstrate

(*a*) that the xylem of a plant conducts water, and

(*b*) that the phloem conducts manufactured food material.

(Do not describe more than two experiments in all.) (L.M.)

9. Give an account of the process of secondary thickening in the stem of a dicotyledon.

10. Give an account of the structure of a cross-section through the branch of a tree, as observed with the eye and a lens, and state the functions of the parts. (J.M.B. Matric.)

11. A woody shoot showing three years' growth is cut longitudinally down the middle from the apex to the base. Draw a diagram to show the annual additions of wood as they would be seen at the exposed surface, and attach the date of formation to each of the zones drawn. (C.S.)

12. Explain the botanical nature of (*a*) bottle cork, (*b*) " grain " of wood, (*c*) knots in wood. (C.S. part question.)

13. Give an account of the development and structure of cork (including the lenticels). In what parts of plants is cork formed, and what is its use to the plant ?

14. Describe an experiment to demonstrate that a green shoot respires.

By what means does a supply of air for respiration reach all the living cells of a tree ? Refer especially in your answer to the most actively growing cells. (J.M.B., Hr. Sch. Cert.)

15. Describe a lenticel and explain in detail why lenticels are sometimes necessary in a plant. (C.J.)

16. Which parts of a green plant are chiefly concerned with its growth ? How does a main root differ from a main shoot in

(*a*) its manner of growth ;

(*b*) its method of branching ? (J.M.B. Matric.)

CHAPTER X.

ERECT STEMS OF HERBS AND TREES.

20. ERECT HERBACEOUS STEMS.

PRACTICAL.

1. The strengthening of erect stems. (*a*) *By turgescence.*—Cut off any erect herbaceous stem close to the ground, and leave it exposed to light and air. Observe that after a time it becomes limp. Explain.

Split a similar fresh herbaceous stem in half lengthwise, and observe that each half becomes curved. Has (i) the skin, (ii) the internal tissue contracted or expanded? Which was under tension and which under compression in the uninjured stem?

(*b*) *By the position of hard tissues.*—Find the weight a straw will carry (supporting it by the ends in a horizontal position, and adding weights to the lid of a tin box hanging from the middle). Then split a similar straw into strips, tie them together, and find the weight which the bundle of strips will support.

Cut thin transverse sections of the stems of various herbaceous plants, and make diagrams to show the positions of the stiffening tissues.

Advantages of the erect habit.—A plant gains obvious advantages by being able to produce leaves (as well as flowers and fruits) at successively greater heights above the ground, instead of at one level only. For not only are the leaves on an erect stem much less likely to interfere with each other's light supply; they are also in less danger of being overshadowed by neighbouring plants. Where every inch of ground space is keenly contested, the skyscraper will naturally oust the bungalow. Moreover, an erect stem offers scope for the development of branches

on all sides. It is therefore significant to find that the "higher" plants have usually stems endowed with a remarkable impulse to vertically erect growth (pp. 240 to 242). These advantages, however, must be paid for by the expenditure of a great deal of energy, and in most cases by the formation of special stiffening tissues.

The force of erect growth.—Upward growth is carried out with a persistence which often represents the exertion of great force. This force can be estimated by allowing the growing tip of the stem to push upwards against a weight suspended above it from a spring balance. A cardboard collar (*e.g.* a small pill box) may be fastened to the base of the weight to prevent the tip of the plant from slipping aside. The amount by which the first weight recorded on the scale is lessened by the pressure of the plant below is a measure of the force which the tip region exerts in its upward growth. It is this force which enables the stems of seedlings, and the erect shoots growing in spring from underground rhizomes, bulbs, etc., to push aside the soil which covers them.

The maintenance of the erect position by herbaceous stems.—The stiffness of the juicy stems of many herbaceous plants, especially when young, is chiefly due to *turgescence*, that is, to the distension of their cells with watery sap, as a result of **osmotic pressure** (p. 94). A length of six inches or so of thin rubber tubing, such as is used for joining glass tubes, cannot support its own weight in an erect position when held by the end. But six inches of such tubing, distended with water at the tap and tied at the ends, is stiff, and can be held erect easily without side support. The soft juicy tissue in the interior of a herbaceous stem is similarly held stiff by the elastic skin (epidermis). If such a turgid stem is allowed to wither, it quickly becomes weak and limp, as the internal pressure of the sap becomes lessened by evaporation of water. In a turgid herbaceous stem the epidermis is in a state of tension or stretching, while the interior is in a state of compression owing to osmotic pressure. This is easily shown (Fig. 110) by splitting the stem along its length, when the pieces curve outwards from each other, the epidermis (contracting now that the pressure of the inside of

the stem is removed) being on the concave side, while the inner tissues (taking up more room now the compression of the stretched epidermis is removed) are on the convex side.

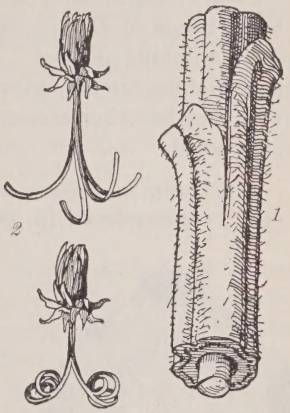


FIG. 110.—1. Shoot of Sunflower, with the leaves removed and the pith separated from the peripheral tissues by means of a cork-borer. 2. Stalk of the inflorescence of Dandelion, split longitudinally by two incisions at right angles to one another: *a*, just after splitting; *b*, after immersion in water. (After Strasburger.)

Most erect herbaceous stems are additionally, and in some cases chiefly, strengthened by strands and sheets of **stiffening material** so placed that the maximum effect is obtained with the minimum of material. To understand this we must bear in mind that the chief danger to an erect stem is that of being broken by the horizontal pressure of the wind. When the stem bends before the breeze, the lee side is plainly compressed, while the windward side is stretched. Somewhere between these two extremes there must be a "neutral" region which is neither compressed nor stretched. Evidently the *outside* parts of the stem suffer the greatest strain and have most need of support. If the wind blew in one direction only, a vertical strand of stiffening material on the windward side and another on the leeward side—each *as near the outside as possible*—would meet the needs of the case, since the ground tissue (pith, cortex and other "packing" parenchyma) would keep the strands from shifting. Wind, however, may blow from any point of the compass, so that the strengthening strands are needed on all sides. A large number of such strands is, of course, the same thing as a complete cylinder, and this is precisely the arrangement found in a majority of cases (Figs. 94, *sk*, and 111 (2)). The "neutral" region of the interior may then be dispensed with, since it is not subject to strain; this fact explains why although many herbaceous stems become hollow early, they are not thereby weakened, and why the trunks of old and hollow trees do not collapse readily (Fig. 338). The remarkable strength of a grass straw

(Expt. 1, *b*, p. 165) and of the quill of a feather are other examples of the same principle, utilised in hollow columns by engineers.

Such strengthening tissues consist in the simplest cases of the **woody tissues** of the xylem of the vascular bundles, which thus serve a double purpose. The position of the bundles, considered as stiffening tissues, usually so near the surface of erect stems, so near the other stems and middle line of roots, is therefore significant.

The commonest form of tissue used for strengthening purposes only is **sclerenchyma** (p. 96). It very often occurs in the peri-

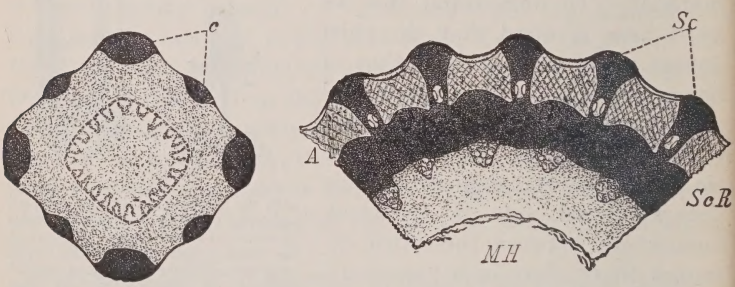


Fig. 111.—Rigidity against the bending of stems. 1. Transverse section of a young twig of Elder; *c*, collenchyma. 2. Part of a transverse section of a haulm of Purple Moorgrass; *Sc*, ribs of sclerenchyma; *ScR*, sclerenchymatous ring connecting them laterally; *A*, green assimilating tissue; *MH*, pith cavity. (After Noll.) (Magnified.)

cycle, either as a continuous zone (Fig. 94), or as fibres running along the length of the stem just outside the phloem of the vascular bundles, which they support in the manner of splints (*e.g.* sunflower). Another common condition is for a cylinder of sclerenchyma to support each vascular bundle (*e.g.* maize, buttercup (Fig. 96)). Sclerenchyma strands in the cortex are common in ribbed or fluted stems (Fig. 111, 2).

In the younger parts of the stem, which are still elongating, sclerenchyma is not yet developed. In these regions (Fig. 111, 1) the cells of the outer cortex form a special strengthening tissue called **collenchyma**, more valuable at this stage than sclerenchyma because it can stretch considerably without injury. The walls of these cells are noticeably thickened at the corners and also on the sides of the cell parallel to the stem-surface (Fig. 64). The thickening thus forms a number of concentric cylinders

round the stem in the best possible position, *i.e.* just under the surface. The tissue as a whole, though composed of cells which are individually soft and weak, therefore combines considerable mechanical strength with the power—necessary in a rapidly growing region—of changing readily in shape, as a thin sheet of rubber would; while at the same time it can carry on the work of photosynthesis, etc. (p. 147). Collenchyma is specially abundant just below the surface in the "ribs" of fluted stems.

Sclerenchyma and collenchyma are sometimes referred to collectively as **stereome**.

GRASSES.

Grasses.—The grasses, as the main source of the food of man and his domestic animals, are the most important, economically, of all herbaceous plants; and their stems provide a specialised and highly interesting example of the erect habit which may be usefully compared and contrasted with dicotyledonous herbs on the one hand and with trees on the other.

Habit of growth.—Most grasses spread by **prostrate creeping shoots**, which spring from the axils of the lower leaves and then run on in all directions, sometimes above, more often below, the soil in a close turf-forming network (*e.g.* couch grass, meadow foxtail, sheep's fescue). The prostrate branches in their turn produce abundant erect flowering shoots (*culms* or *haulms*). In some of the more deeply rooted grasses (*e.g.* wheat, cocksfoot, meadow fescue) the numerous branches, arising in the axils of the lower leaves of the original plant, grow erect (Fig. 308); branches from the bases of these behave similarly, with the result that perhaps a hundred or more haulms may develop from one seedling. This habit of growth, called "tillering," produces compact tufts or tussocks. The thick growth of perennial grasses is notably encouraged by mechanical injury—mowing and rolling, grazing and treading by animals, etc. In British species the haulms often reach a height of four feet or more; reeds and certain tropical grasses (*e.g.* bamboo and sugar cane) are much taller.

The **leaves** are abundant and arranged alternately, with a phyllotaxis of $\frac{1}{2}$ (p. 47). The blade is simple, long, linear in shape, parallel-veined, and more or less erect, especially

in its early stages. The lower end of the blade merges into a cylindrical and usually split sheath, which closely embraces the stem to which it is attached, and—since the nodes are for some time close together—may also enclose the sheaths of several upper leaves. At the junction of blade and sheath, the grass leaf bears, on its upper surface, a little

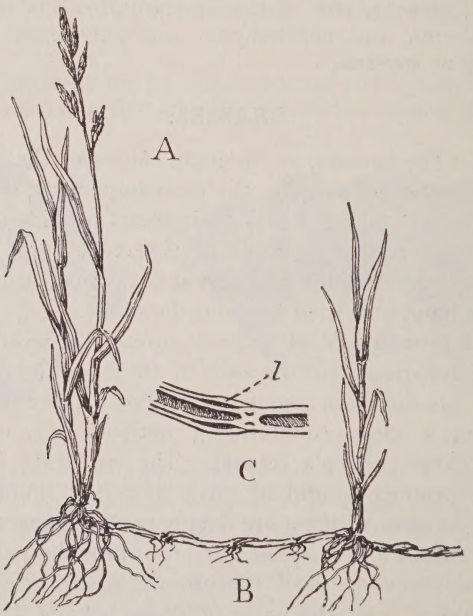


FIG. 112.—Habit of growth of a grass: *A*, aerial stem terminating in a branched inflorescence; *B*, underground branch sending up a new shoot from one of the nodes; *C*, section through the node of a stem that has been placed horizontal, showing the sheathing leaf-base *l*, and the beginning of the upward curvature of the stem (compare Fig. 157). (From Curtis.)

membranous outgrowth called a *ligule*, which probably serves to keep rain out of the sheath. The **"telescoped" leaf bases** (Fig. 109, *l*, *b*) are a characteristic feature of grasses, and account for not a little of their success. These concentric cylinders are quite strong enough to hold several leaf blades well above the top of the young haulm, and so to permit active photosynthesis and transpiration whilst protecting the flowers which are developing at the upper end of the haulm.

When the flowers (p. 420) are almost ready to open, the haulm begins to grow very rapidly in a manner suggesting the drawing out of telescope tubes; its internodes elongate so quickly that the internal tissues are torn, and the flowering stem becomes a hollow straw, except at the nodes, where there are horizontal shelves (Fig. 111 (2), and Fig. 112, *C*). It hardens and stiffens as it grows, so that when the spikelets of flowers at its upper end open, they are carried high above the leaves on a slender but very strong rod, which bends and dances in the wind, and allows the pollen to be detached and blown to the stigmas of other flowers. The great strength of a grass straw (Expt. 1, *b*, p. 165) is partly due to the presence, in the epidermis, of silica, the substance of which rock crystal and ordinary sand are composed. When a straw is burnt, the silica remains as a hollow cylinder of mineral matter. It is also very apparent in a bamboo stem, which readily turns the edge of a pocket knife.

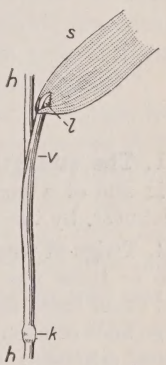


Fig. 113.—Part of a Grass Stem and Leaf. *h*, haulm; *s*, part of leaf-blade; *l*, ligule; *v*, leaf-sheath; *k*, swelling at base of leaf-sheath. ($\times \frac{1}{2}$.) (After Schenck.)

Should the erect shoots of a grass—in spite of the special **adaptations for remaining upright** which have been described—be laid flat by wind or heavy rain, they can raise themselves again by means of the *intercalary growing points* just above each node (Figs. 112, *C*, *l*, and 157). These are slightly swollen masses of soft tissue which—when the stem is not vertical—are stimulated by gravity to grow unequally until the erect position of the shoot is regained.*

The **roots** of grasses are of the usual monocotyledonous type, *i.e.* adventitious and usually fibrous. They spring from the lower nodes of the stem, and spread more or less horizontally in the soil. In some cases (*e.g.* maize, Fig. 109) special "prop roots" grow out from the stem above the soil, and, gripping the earth with their root hairs, act as stays or guy ropes which often save

* Plants of the dicotyledon family Caryophyllaceae (p. 378) have intercalary growing points, acting similarly, at the nodes themselves.

the plant from being blown down or uprooted by the wind. Grasses as a family are essentially shallow-rooted, and their water supply is obtained from the upper layers of the soil. If the upper soil, therefore, remains moist during the growing period, grasses can flourish in places where plants with large and deep roots (*e.g.* trees and shrubs) would find the water supply insufficient.

21. THE TREE HABIT.

PRACTICAL.

1. The strength of wood.—Compare the strength of a woody twig and of a herbaceous stem or branch of the same length and thickness, by the method of Expt. 1, *b*, p. 165.

2. Twigs of trees.—In February or early March cut off twigs, two or three feet long, of horse chestnut, sycamore, beech, oak and other trees, and keep them in water in a warm room. Dissect large buds of each, and notice the nature of the bud scales (*e.g.* leaf bases, stipules). On resting winter twigs identify lenticels, leaf scars, bud-scale scars, and the length which grew in each of the previous three seasons. Compare transverse sections of the growth of these seasons. Show and name these features on sketches. In spring make sketches showing the stages of natural unfolding of the buds.

Trees and shrubs.—A **tree** is a woody plant having a tall, self-supporting main stem (trunk) with well-developed internodes, and therefore giving off branches at successive heights above the ground. A woody plant, the stem of which branches most freely near the base, is conveniently distinguished as a **shrub.**

The stems of the trees and shrubs, which (owing to the characteristic persistence of their old branches and the periodical formation of new branches) have to bear an increasingly great weight and withstand the side pressure of the wind, derive their strength from *wood*, which from an early stage forms a very large proportion of the whole bulk. In many cases (p. 155) most of the wood serves for support only, the outer layers (the "sap wood") being sufficient to supply the leaves with all the soil water they need.

Woody and herbaceous plants compared.—As compared with other erect plants, trees and shrubs have further marked advantages. Being **able to form bark** (p. 159), not only can these plants safely practise secondary thickening, with its great benefits (p. 153), to an extent which would be otherwise impossible; the possession of bark also saves them from the risk, which besets herbaceous plants, of transpiration from the stem in winter (p. 86). Thus, while most of our herbaceous plants can escape the danger only by sacrificing all parts above ground before winter, trees and shrubs need merely to shed their leaves.* It follows that each spring, in the great race for light, the herbaceous plant is handicapped by having to start always at the ground level; whilst the tree's leaf-buds are already raised high in the air, ready to unfold. A further difference is that the new shoots of most herbaceous perennials—formed from buds at or below the ground level—become separated and grow independently; whereas trees and shrubs **increase in size from year to year** by the extension of the branches of a single main stem and a single main root until the stage is reached (in British forest trees usually at an age of 30 to 50 years) when seed-production puts a stop to growth in size by using up the surplus food made. Shrubs flower earlier, and therefore remain smaller, than trees.

The history of a sycamore twig.—The characteristic habit of growth of trees may be best understood by following for a year the fate of the buds borne by the twig of a tree. It is convenient to begin by studying a twig of a sycamore.

The twigs in summer.—In summer the younger twigs of the sycamore bear large five-pointed leaves (Figs. 33 and 114), the veins of which are reticulate and palmate. By variation in length of the leaf stalks, and by twisting of the stalks when necessary, the blades are placed at right angles to the light and a very perfect leaf mosaic is often produced. The leaves are opposite

* **Evergreen trees** (*e.g.* holly, holm oak, ivy, pines and firs) **and shrubs** (*e.g.* rhododendron), which invariably have leaves adapted (by thick cuticle on the epidermis and other characters, p. 84) to transpire slowly, can avoid the sacrifice. On the other hand, they pay for the immunity by a correspondingly slow rate of photosynthesis during the summer, when the leaves of deciduous trees are in full activity.

and decussate, and since each normally bears a bud in its axil, the buds along the twig are also, from the first, in pairs, each pair being at right angles to the pair next above or below. At the very tip of the twig is a larger "terminal" bud.

Fig. 114.—Leafy branch of Sycamore, with fruits.

Autumn colours and the fall of the leaf.—As the summer wanes, the soil becomes colder, and the chilled roots lose much of their power of absorbing moisture. The leaves have finished their work, and their **transpiration is becoming dangerous**; one by one they fall off. But this does not take place until certain preparations have been made. In the medullary rays and elsewhere starch and other foods have already been stored up in quantity sufficient to supply the needs of the winter and the early spring. The chlorophyll of the leaves breaks up; the part which may still be useful to the plant drains into the stem, leaving little heaps of yellow grains behind. Or a special colouring matter may be formed, which, united in various ways with the materials of the dying leaf, gives the warm shades of red, orange, and purple which make the woods so beautiful in autumn.

When all is ready, a layer of cork (Fig. 115, *c*) forms at the junction of the leaf stalk and the twig, and consequently no raw wound is left when the leaf-base splits across—along a plane of weakness (the "**absciss layer**") which has formed just above the cork layer—and the leaf flutters to the ground, there to rot and enrich the soil.

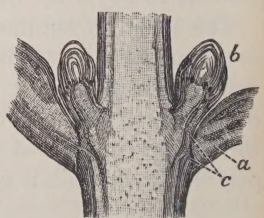


Fig. 115.—Longitudinal section of twig of Sycamore in autumn. *a*, base of leaf; *b*, axillary bud; *c*, cork layer. (× 2.)

The leaf scars.—The former position of each leaf is now marked by a curved scar (*l.s.*, Fig. 116), and a row of brown dots

(*v.b.*) in the scar still shows where the vascular bundles bent outwards from the twig into the leaf. A line (*a*) stretches across and joins the two scars of each pair.

The resting buds.—Just above every scar is the bud which arose in the axil of the fallen leaf. It is covered with overlapping scales of light green colour. At the end of the twig is the single terminal bud, similar in appearance to the axillary buds, but of larger size.

It is instructive to take the terminal bud of a winter twig to pieces. The outer scales are tough and green, while the inner ones are thinner and are covered with hairs which give them a beautiful silvery appearance. Usually there are fourteen scales. Each is long and narrow, and at its upper end the rudiment of a leaf blade is often to be seen as a few teeth. The bud scales of the sycamore are equivalent to the leaf bases only of foliage leaves, the stalks and blades of which have failed to develop.

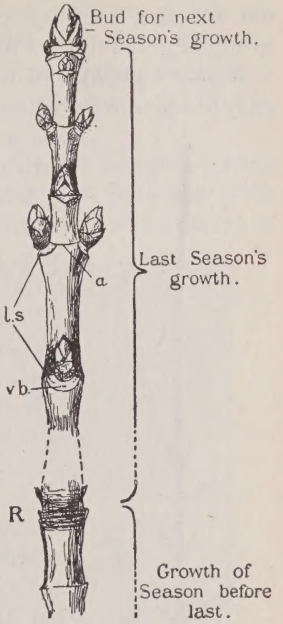


FIG. 116.—Sycamore twig in winter. *l.s*, leaf scars; *vb.*, ends of vascular bundles; *R*, rings of scars left by scales of last winter's terminal bud. (Slightly reduced.)

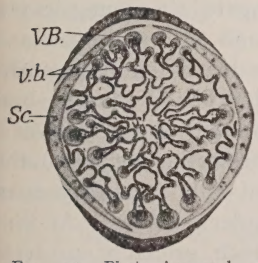


FIG. 117.—Photomicrograph of leaf-bud of Sycamore, in transverse section. *V.B.*, midrib; *v.b.*, smaller veins (vascular bundles); *Sc.*, scale. (× 2½.) Compare with Fig. 119. (T. D. Tuton Hall.)

When all the scales have been removed there remain—standing on the sides of the cone which ends in the "growing point"—one or two pairs of delicate green foliage leaves, surrounded by a little down. Each leaf is folded fanwise, as is shown in Figs. 117 and 119. It will be noticed that the veins (*V.B.*, *v.b.*) of the leaves are nearest the *outside* of the bud. The large sheaths (*Sc.*) surrounding the two pairs of young foliage leaves are

four of the overlapping scales. In a large terminal bud a group of green flowers may often be found (Fig. 314).

A year's growth.—On the leafless winter-twig of a tree it is easy to see which portion grew out the previous season. This part has a thinner, smoother and lighter-coloured bark than the older regions of the twig, and it does not usually bear branches, but buds only. It is, moreover, marked off quite clearly from the rest by the close-set rings of bud-scale scars ("girdle scars") at its base (Fig. 116, *R*). Similar sets of rings still mark the previous positions of the terminal bud (*i.e.* the previous positions of the end of the twig), one, two, three, or even four or more years ago; so that by their means the history of the branch may be traced for some years and each portion dated (see also Fig. 100). A branch which has grown normally shows, when examined in winter, buds on the last season's growth, new twigs on the growth of the season before last (Fig. 118), twigs branched once on the next older part, and so on.

FIG. 118.—Two-year-old twig of Sycamore in winter. (× ⅔.)

The new twigs.—About the middle of April the tree awakes to renewed activity. The stored food makes its way to the buds; invigorated by the rich sugary sap, their "growing points" push forward, the internodes separating the young foliage leaves elongate, the young leaves swell, burst apart the scales (Figs. 119 and 314), and open out their folds to the light and air; and new leaves—indistinguishable in the resting bud—grow out and expand. As the bud unfolds, the leaves necessarily first present their "lower" surfaces (which are protected by the projecting veins) to the trying weather of the early spring, and only gradually open out the pleats which shield the more tender portions. At first they are of a beautiful red colour, which probably protects them from the injurious effects of too intense light, but as they become larger the red colour fades and the essential green of the leaves is revealed. The internodes between the bud-

scales do not elongate, and therefore when these scales fall off they leave close-set rings of "girdle scars" (*R*, Fig. 116) on the twig as a record of their former position. The events just described can be hastened by keeping a winter twig (dipping into water) in a warm room.

The elongation of the new portions of stem proceeds during spring and summer, the length of each internode being some index of the vigour of the twig at the time; it reaches a

Photo. Henry Irving.

FIG. 119.—Four stages in the opening of a Sycamore bud. (See also Fig. 314.)

maximum in early summer. As autumn approaches, the new internodes remain shorter and shorter, and except for some two pairs at the tip, the newest leaves remain stunted, consisting of leaf bases only. They continue to grow in length for some little time after the growing-point of the twig has come to rest, however, and therefore close over it in the manner characteristic of bud scales.

It is usual for the axillary buds of herbaceous plants to grow out whilst the leaves subtending them are still vigorous. In deciduous trees, on the contrary, such buds do not develop into side twigs until the following season, unless the circumstances are exceptional. If, however, the leaves of a tree are destroyed (*e.g.*

by insects* or spring frosts), or if the supply of available food is abnormally large, some of their axillary buds may develop into leafy twigs during the summer preceding the spring in which they would normally have grown out. Such precocious leafy shoots are called Lammas shoots. Other exceptions are found in the flowering shoots of hazel and alder (pp. 450 and 452).

In winter the lenticels (p. 160), often looking like pinpricks in the bark, are more or less conspicuous even on the twigs formed the previous spring.

The above description of the seasonal changes undergone by a sycamore twig applies generally to the great majority of such of our trees and shrubs as shed their leaves once a year and are therefore said to be **deciduous.**

EXERCISES X.

1. What advantage is it to a plant that its stem should be erect? In what way can you measure (*a*) the rate, (*b*) the force, of upright growth in an erect stem?

2. Describe the means by which the rigidity of plants is maintained. (C.S.)

3. Explain with the aid of diagrams how the structure and arrangement of the tissues in the stem of a sunflower (or bamboo) enable it to grow in an upright position and to withstand the effects of wind without breaking. (C.S.)

4. Describe (*a*) the resemblances and (*b*) the differences between a tree and a herbaceous plant. (J.M.B. Matric.)

5. How do the following plant-organs maintain an upright position: the young stem of asparagus, the daffodil leaf, the mature stem of a sunflower and the trunk of a forest tree? (L.M.)

6. What are the essential differences in structure and method of growth between the upright stem of a grass and the stem of an herbaceous dicotyledon? (C.S.)

7. Describe in detail the leaves and roots of any named grass.

8. Write an account of leaf-fall in the case of some well-known tree. (C.J.)

9. Describe the structure of any winter resting bud, showing the nature of the different parts. Why are many trees leafless during a part of the year? (N.F.U.)

* This frequently happens with "pedunculate" oaks (p. 443.) as a result of the attacks of the caterpillars of a small green moth, *Tortrix viridana.*

10. Give large well-labelled drawings to show the structure of the winter-bud (or resting-bud) of any tree you have studied. What becomes of the various parts when the bud opens in spring ? (C. P.)

11. How is it that the leaves of our deciduous trees are shed in autumn ? Of what benefit to a plant is the deciduous habit ? By what means are the leaves of these plants renewed in the following spring ? (O.S.)

12. Describe and explain the changes in the external appearance of the shoot of any deciduous tree during the first few years of its growth. (C.J.)

13. By what means would you determine the age of a twig or branch of any tree ? Give diagrams to illustrate your answer. (C. P.)

14. Make explanatory drawings to illustrate the structure of the specimen provided (winter twig of horse chestnut). Name all the parts of your drawing. (O.J.)

15. A branch, one centimetre in thickness at its base, has just been cut off from a tree. State how you would attempt to discover how many years it had been growing on the tree. How could you verify your observation ? (C.J.)

16. Describe the various devices adopted by a sycamore tree to control evaporation from stem, leaf, bud and seed. (J.M.B. Jun. Cert.)

CHAPTER XI.

COMPENSATIONS FOR WEAKNESS OF STEM.

22. CLIMBING PLANTS.

PRACTICAL.

1. Etiolation of plants in dim light.—Grow pea seedlings in a pot at a distance of some yards from a window, and compare them with seedlings of the same age grown on the window sill. How do the two sets differ in length of stem, size and colour of leaves, strength of stem ?

2. Scramblers.—Study young shoots of dogrose and bramble, and compare those growing on the open heath with others growing in hedgerows. In which place are arched shoots commoner ? Why ? How are the shoots prevented from falling under their own weight in the hedge ? What parts of the stems and leaves produce prickles ? How are the prickles curved ? Would they be equally useful if their points were directed towards the tip of the shoot ? Try to push off a prickle (*a*) sideways, (*b*) lengthways. Find out if it is a little branch or merely an extension of the outer tissues.

How do the tips of fallen shoots of dogrose and bramble behave ?

Compare them with cleavers or goosegrass. Study the seedlings (common under hedges in early spring). How high can the stem grow without support ? How does the tip of a fallen shoot behave ? Examine the stem and leaves with a lens to see the down-pointing prickles.

3. Twining stems.—Grow scarlet runner plants from seeds in pots in a good light. At what stage does the stem first seem too weak to continue growing erect ? At this stage mark a point vertically below the tip (using a weighted thread as plumb-line) and repeat the observation at intervals of half-an-hour until the tip has described a complete revolution. What is the time of a

complete revolution ? Is the direction of revolution clockwise (*i.e.* the same as that of the hands of a watch lying face upwards) or counter-clockwise ?

Mark a stem with Indian ink at equal intervals, put a long stick vertically into the soil near the stem, and when the stem by revolving touches the stick notice whether the part below this point of contact continues to revolve or stops. Try to discover, by observing the ink marks, whether any of the revolving part of the stem has finished growing in length. With other plants find out (by cutting successive pieces from the upper part) how much of the stem takes part in the revolution. Find out whether the stem will twine round a horizontal stick. If not, how far from the vertical may the stick be ?

Make similar observations (especially in regard to direction of twining and possible slope of support) upon the twining stems of great and small bindweed, dodder, hop (notice the prickles on the stem ; do they make it easier for the plant to climb ?), honeysuckle, black bindweed, woody nightshade (bittersweet), black bryony (*Tamus*). Notice in all these that the leaves near the apex remain small until a grip of the support is obtained. What is the advantage of this ?

4. Tendril climbers.—Examine plants of sweet pea, garden pea, various vetches, grape vine, passion flower, white bryony, cucumber and vegetable marrow. Try to find out in each case whether the tendril is a modified leaf, leaflet, or stem-branch (see pp. 55 and 147). Watch a plant day by day until a free tendril grasps a support, and notice how it *afterwards* becomes spirally coiled. In what respects does its behaviour resemble and differ from that of a twining stem ? Can you straighten the tendril by pulling, without leaving any kinks ? Explain. Is the spiral of the tendril continuous or does it change its direction in the middle ?

Wind wire round a pencil to make a *continuous* spiral spring, and notice the kinks formed when the wire is straightened by pulling the ends. Is a continuous or a reversed spiral better for the plant in a gale of wind ? Why ? In what way does the plant gain by the coiling of the tendril to form a spring, *after* it has seized the support ? Compare the strength of an old and a young tendril. Account for the difference.

Gently rub various unattached tendrils at one place for a few minutes (*a*) with a rough, (*b*) with a smooth object, and describe any resulting movement. Tendrils of white bryony and passion flower answer well.

Notice the sucker-like tendrils of the Virginian creeper (*Ampelopsis Veitchii*), and the way in which they fix the plant to the wall. What evidence is there that they are modified branches and that the stem bearing them is a sympodium (p. 148). Examine again the tendrils of vine, and notice whether they behave in any special manner if their tips touch a wall or other firm surface instead of the usual support.

Examine a climbing tropaeolum or "canary creeper" (often, though wrongly, called nasturtium), and observe that the *leaf stalks* act as tendrils. Describe the behaviour of (*a*) the leaf blade, (*b*) the leaf stalk before and after the support is grasped. Watch a young plant coming up; does the stem revolve before the leaf stalks come into contact with the supports?

Compare with this the method of climbing of *Clematis*.

Make transverse sections of the stems of all herbaceous climbers studied, and compare the diameter of the central cylinder with that of an equally thick self-supporting herbaceous stem.

5. The ivy.—Study the bristly adventitious roots which attach the young twigs to a wall or tree. Make sections through the points of origin of the most recent roots, and convince yourself that they arise from the central cylinder of the twigs and therefore (p. 147) cannot be stem branches. Sketch good examples of leaf mosaic. How do the leaves, formed after ivy reaches the top of a wall, differ from the lower leaves? Does the stem put out climbing roots above the top of the wall? Cover a little of the young stem of this region with black cloth to keep it in the dark. Do roots grow on the darkened part?

Climbing plants.—In the climbers we have examples of plants which do not make enough stiffening material (p. 167) to hold more than a short length of stem erect, and yet gain all the advantages of the erect habit (p. 165) because they are able to attach themselves to stronger plants or other supports, near which they may happen to spring up. On the one hand, the climber in favourable circumstances saves the material and energy which self-supporting plants must devote to the formation and maintenance of a strong stem; and thus at a minimum cost it quickly reaches a height favourable to the activity of leaves, flowers and fruit. On the other hand, the seed of a climber often germinates in a place affording no outside support, and is

so handicapped that it soon succumbs. Climbing plants are so common in hedges and woods because, in general, those which spring up in such situations have full scope for the exercise of their special powers, and therefore a greater proportion survive there than in other places.

Scramblers.—In weakness of stem, length of internodes and (before attachment) smallness of leaves, climbing plants recall the etiolated condition (p. 66) of plants grown in a dim light. In etiolated plants, however, the leaves are not only small but also pale in colour, owing to the lack of chlorophyll. It is easy to see that the etiolated condition—the rapid growth of a long and almost leafless stem—is of advantage to a seedling in thick undergrowth, because it enables the plant to push through crevices and reach the light with the least possible delay and obstruction, the expansion of its leaves being postponed until they have a chance of being useful.

Such a "scrambling" habit may be seen in hedges, in chick weeds and other "occasional climbers" which in an open place produce shorter but self-supporting stems. It has become the one condition of success in goosegrass or cleavers (Fig. 181) —a herbaceous annual plant with a weak stem and apparently whorled leaves (both covered with small backwardly-pointing prickles), which appears in great numbers from seeds in early spring in hedges. If such a seedling springs up in flat open ground its stem soon bends to the ground under its own weight, and a certain length being there supported the tip turns up again, to fall once more after a little further growth. The process is repeated, the tip turning up repeatedly after each collapse, and thus, as it were, testing the possibilities in various directions. Among other plants, however, it does not fall to the ground; its weight, on the contrary, is supported by neighbouring leaves, etc., on which its small hooks happen to catch, leaving the tip free for continual upward growth.

The same behaviour is to be seen in the dog rose and bramble (blackberry), the upward shoots of which may grow unsupported to a height of several feet, but then arch over (Fig. 120) so that their tips rest on the ground or some other support and, being thus relieved from the weight behind, once more turn upwards,

or take root (p. 196). In a hedge, however, the backwardly-pointing prickles (Fig. 35) catching on stronger vegetation prop them up, and the arched habit is less common, while the bushes, if unmolested by man, grow to greater height than in the open. Such prickles are outgrowths of surface tissues only, and are not branches.

Photo Henry Irving.

FIG. 120.—Blackberry (bramble), arched habit.

Twining stems.—It may be observed in the early stages—not merely of climbers, but of most flowering plants—that the stem at first grows straight up. Presently the tip begins to wander slowly round and round as it moves upwards, and so follows a spiral path in the air. This spiral motion is called *circumnutation.*

In plants with twining stems (such as scarlet runner, bean, convolvulus, hop, etc.) circumnutation is more marked than in

non-climbers—possibly the tip "leans" out more from the vertical because the stem is weaker—and the upper portion of the stem sweeps round a wider circle. It is easy to show that *only the young portion which is still growing in length* takes part in the swing to each point of the compass in succession. Should this region of the stem encounter a support of suitable thickness and sufficiently erect, the motion below the point of contact ceases; the upper part continues its course and consequently winds round the support. The plant is prevented from slipping by the friction between the stem and the support (increased, in the case of the hop, by prickles on the stem), and by the additional anchorage obtained when its leaves expand and rest on neighbouring projections. It follows that the only weight to be supported by the stem is the free upper portion which is still wandering round as it grows upwards.

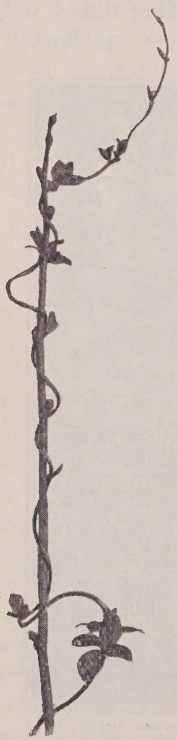


Photo. Henry Irving.

FIG. 121.—Young Honeysuckle climbing a shoot of Hazel.

It may be observed that the leaves on the upper, unattached part of a twining stem remain small, and so do not interfere with the explorations of the tip region; once a grip has been obtained, however, they expand to their full size.

The stems of honeysuckle (Fig. 121), hop and black bryony (Fig. 182) turn in the same direction as the hands of a watch lying face up. This is called the "clockwise" direction. On the other hand, the greater and lesser bindweed (Fig. 122), the runner bean, dodder (Fig. 146), and most other twining stems are "counter-clockwise" climbers. The stem of woody nightshade (bittersweet) revolves indifferently in either direction.

The lesser bindweed (convolvulus) differs from most twiners in being able to twine round a horizontal support, a fact which

suggests that its stems are sensitive to contact somewhat as tendrils are (p. 188).

Sensitive clasping organs.—These are seen in their simplest form in the **leaf stalks** of the clematis (old man's beard) and climbing tropaeolum (canary creeper). The stem itself revolves, and the leaf blades at first remain very small, so that the leaf

Photo. Henry Irving.

FIG. 122.—Lesser Bindweed (Convolvulus) on Oat stem.

stalks have every opportunity of finding suitable supports, around which they twine. The leaf blades, brought to face the light, then expand, while the stalks harden. In this way the weight below the place of attachment is borne by the support, and the weak but rapidly lengthening upper part is free to reach other points of vantage. In the climbing fumitory, the narrow segments of the compound **leaf blades** are similarly sensitive and able to grasp supports.

Tendrils.—Most wonderful of all climbing organs are the threads called **tendrils.** When its end has touched and then twined round a support, the tendril forms itself into a spiral which, like a wire spring, draws the plant up to the support, and yet can lengthen and yield to the wind when necessary. As both ends of the tendril are fixed before it coils, there is necessarily a point where the direction of the spiral is reversed. Thus the whole tendril can be straightened without forming kinks. The "spring," at first soft and tender, soon hardens so that it can withstand a considerable pull without breaking.

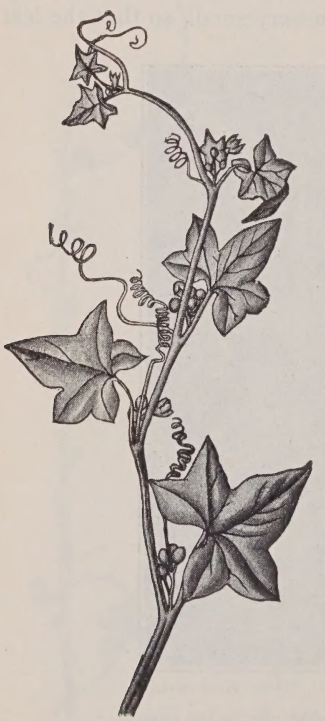


Fig. 123.—White Bryony. Flowering branch, with tendrils. Reduced. (After Strasburger.)

Actual friction and not mere contact of a tendril with a support is needed to cause the curvature which results in coiling. Such friction is secured by the almost incessant movement of plants by the air. Its effect may be studied by gently rubbing a *turgid* tendril of either vine or white bryony (perhaps the most perfect tendril-climber) in one place for some minutes. A rough stick is found to produce a quick response (often noticeable in half a minute), whereas a smooth glass rod has very little effect. The friction stimulates more rapid growth on the opposite side of the tendril, and the latter therefore hooks gradually round the object rubbing it. Only the part close to the support is affected by the friction.

Morphology of tendrils.—In most cases tendrils are **modified leaves or parts of leaves,** in which the sensitiveness to contact, or rather to friction, seen in the leaves of the clematis, tropaeolum and climbing fumitory, is very highly developed. Such tendrils are well shown by various peas and vetches. In the sweet pea, the meadow vetch and the everlasting pea, every leaflet except the lowest pair has become modified into a slight but strong

tendril. The sacrifice of so much of the leaf surface of these plants to form tendrils is compensated for by the flattening of

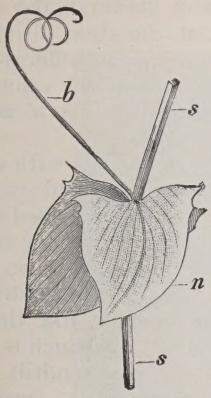


FIG. 124.—Yellow Vetchling. *s*, stem; *n*, stipules; *b*, leaf-tendrils. ½ nat. size. (After Schenck.)

FIG. 125.—A vine tendril is a modified inflorescence. (After Gilg.)

the stems. Such " winged stems " act as leaves and carry out photosynthesis and transpiration.

In the yellow vetchling (Fig. 124) the whole leaf blade is represented by a single tendril (in some cases slightly branched), and photosynthesis is carried out by greatly enlarged stipules. An intermediate condition is found in the garden pea (Fig. 43), the tufted vetch, and common vetch or tare, in which the lower leaflets (3, 4 or 5 pairs) remain, the upper leaflets being modified to form tendrils. In smilax it is the stipules which are transformed into tendrils.

The tendrils of the passion flower are evidently **modified branches**, since they grow in the axils of foliage leaves.

The morphology of the vine tendril—at first sight puzzling—can be understood by an instructive application of the rule that in flowering plants, stem branches arise in the axils of foliage leaves. In the vine the tendril is opposite a foliage leaf. It might thus be *either* (*a*) the equivalent of one leaf of a pair of opposite leaves growing on a monopodium (p. 148), *or* (*b*) the real end of a

FIG. 126.—Virginian Creeper. *R*, *R*, stem tendrils. (× ½.) (After Noll.)

sympodium. The latter view is supported by the absence of a bud in the apparent axil of the leaf, and confirmed by the fact that inflorescences (groups of flowers) also often occur opposite leaves (Fig. 125), and that the stem ultimately ends, sometimes in a tendril and sometimes in an inflorescence. A tendril and an inflorescence therefore arise in the same way in the vine. In other words the vine tendril is a **modified inflorescence.**

When the tips of vine tendrils come into contact with a wall or other solid surface they often become flattened to form adhesive cushions. Similar cushions are regularly formed at the rounded ends of the branched tendrils of the Virginian creeper (*Ampelopsis Veitchii*)—a near relative of the vine—when these touch a wall, the plant being thus attached. If the tendrils fail to reach a support they coil up. These tendrils, like those of the vine, grow opposite a leaf (Fig. 126) on a stem which is really a sympodium, and are of the same nature as vine tendrils.

It is doubtful what part has been modified to form the tendrils of the white bryony (Fig. 123), vegetable marrow and cucumber, which all belong to the same family.

Climbing adventitious roots.—The ivy (Fig. 127) supports the weight of its young stem and branches by means of tufts of adventitious *roots* which grow out on the shaded side of the stem, pierce the outer tissues, and coming in contact with a tree trunk or wall give out a sticky fluid which attaches them. The plant obtains its supply of water, however, by a tap-root system in the soil.

Lianes.—Three only of our British climbers—namely, honeysuckle, clematis and ivy—become markedly woody. Woody climbers are, however, very common in tropical forests; they are called *lianes.*

Internal structure of climbing stems.—It has been pointed out (pp. 130 and 167) that roots in the soil are in danger of being broken by the *pull* along their length, set up by the swaying of the leafy stems and branches in the wind; whereas the stems themselves are usually beset by the danger of being broken by pressure from the side. We have seen that the former danger is guarded against by the presence of a narrow *central* core of strengthening material in roots, and the latter by the disposition of hard tissues near the *outsides* of stems. It is therefore interesting to find that in the soft stems of climbing plants—

which are exposed to pulling *along their length* by the force of the wind and the growth of their supporting plants, but are in no danger from side pressures—pith is absent, and the

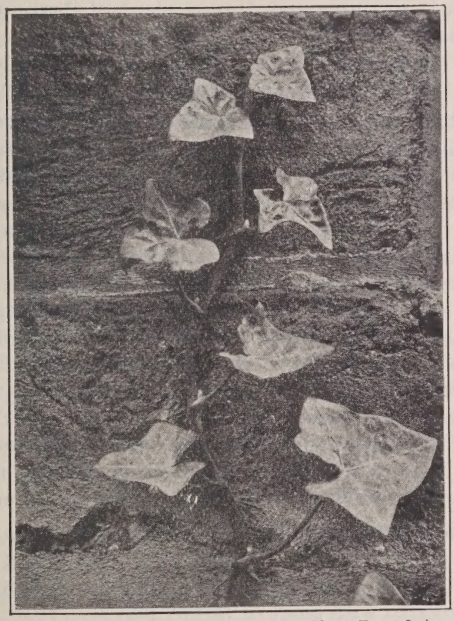


Photo. Henry Irving.

FIG. 127.—Ivy climbing a wall.

strengthening tissue is concentrated in the middle line. The whole central cylinder, indeed, is as narrow as that usual in a root of equal total thickness.

23. PROSTRATE AND ROSETTE-FORMING PLANTS.

PRACTICAL.

1. Stems creeping above ground.—(*a*) Examine a plant of money-wort or "creeping Jenny." Notice the prostrate stem. Does it branch freely? Are the branches axillary? Do any branches grow erect? Does the tip of the stem turn up? Is the stem a monopodium or a sympodium? (give reasons for your conclusion). Is there any arrangement for raising (i) the leaf blades, (ii) the

flowers, above the ground? Can you see any sign of secondary thickening? Where, if at all, are additional roots formed as the plant grows larger? Make a drawing showing all the features mentioned above.

(*b*) Similarly examine and draw a plant of "ground ivy" (not to be confused with true ivy), and answer the questions in (*a*) above. In what respects are (i) the leaves, (ii) the flowers, of ground ivy better exposed than those of creeping Jenny.

2. Branches (runners or stolons) creeping above ground.—(*a*) Study the habit of growth of the stems of creeping buttercup, creeping cinquefoil and strawberry. Does the *tip* of the prostrate shoot turn up? Is the shoot a monopodium or a sympodium? Does it bear scale leaves as well as green foliage leaves? How does the occasional production of small scale leaves instead of large foliage leaves help a creeping plant to reach new ground quickly? Carefully determine and describe the place of origin and the subsequent behaviour of any branches. Where are new roots formed? Make a diagram of each plant showing all these features.

In what respects do bramble branches with rooting tips (p. 185) resemble and differ from runners?

(*b*) *Offsets*.—Dig up a clump of daisy rosettes and wash them free from soil. Examine the manner of connection of neighbouring rosettes by *short* runners called offsets. Compare house-leek.

3. Underground creeping stems (rhizomes). (*a*) *Monopodial*.—Dig up a plant of wood sorrel (in flower Apl.-Aug., Fig. 180); wash away the soil and study the reddish underground stem (rhizome), covered with bases of former leaves. How do you know it is not a root? Does the tip turn up, or does it continue its way through the soil? Do (i) the leaves, (ii) the flowers, grow directly on the rhizome? Does the rhizome form underground branches? Does it form any erect branches bearing foliage leaves? Where do roots grow on the rhizome?

(*b*) *Sympodial*.—Similarly examine dug-up and washed plants of sand-sedge, couch grass, lily of the valley, Solomon's seal, mint, and white deadnettle. In all these observe that the erect shoots bearing green leaves and flowers are formed by the turning up of the *tip* of the rhizome or of its branches; and that the rhizome is continued by horizontal branches arising in the axils of scale leaves. Observe the thickness of the rhizome of Solomon's seal. It is due to stored food, chiefly grape sugar.

4. Suckers.—In dog-rose, mint, white deadnettle, couch grass, yarrow, hazel, apple, or damson, trace the young erect shoots

(which emerge from the soil close to old plants) to their origin underground from leaf axils of a stem-base or of a rhizome. Such short underground shoots are called suckers. How do they differ from (*a*) rhizomes, (*b*) offsets ?

5. "Root stocks."—Dig up, wash and examine plants of primrose, daisy, plantain, dandelion and houseleek. Notice the short stumpy, erect stem (the so-called root stock). How do you know it is not a root ? What are the true roots like ? Look for contractile roots, recognised by transverse wrinkling on their surface. What evidence do you find in the condition of young and old leaves, that these stems grow at the top ? Try to explain why, although they grow at the top, they do not get higher above the surface of the soil.

Find and draw good rosettes of the various plants, and try to discover the phyllotaxis (p. 46). In what respects do the upper and lower leaves of the rosette differ ? Do the lower leaves show any signs of etiolation ? Is the amount of overlapping thereby diminished ? Can you find any other plants growing on the ground covered by the rosette ? Compare "rosette" plants growing in short turf, or on lawns, with others growing among long grass. Account for the difference in habit. Describe how any of these plants may spread horizontally.

The groundlings.—Lacking either the impulse to upward growth or the power of elongating their internodes, the stems of many flowering plants have specialised in utilising to the utmost the possibilities of a life spent on or in the ground, instead of expending materials and energy in the production of a strong erect stem, or (more economically but precariously) relying on the climbing habit, to expose leaves and leafy branches at various heights and on all sides. As a plant habitat, the surface of the soil affords a number of distinct advantages. A creeping stem is evenly supported at a large number of points, and its weight therefore imposes no restrictions on its growth and entails the formation of only a minimum of stiffening material. On the other hand, even a tree (in which the erect habit is seen in greatest perfection) is limited, both in height and in the extent of its branching, by the weight and the wind pressure which its trunk and branches can bear.

The creeping plant is protected alike from the drying effects of, and mechanical damage by, strong winds. The carpet formed by its own foliage prevents rapid evaporation from the soil and thus conserves its own water supply. Being always close to the soil, a creeping stem can put out an indefinite number of effective adventitious roots, and can thus lay under contribution the soil of a much greater area than is accessible to an erect plant of the same size with a root system confined to the neighbourhood of the base of the stem. Assured in this way of ample supplies of soil water for its leaves, the creeping stem can branch on all sides without stint, and explore its surroundings without risk; so that it soon covers the soil with a close mosaic of leaves, which effectually checks the growth of competitors. The part of the plant near each tuft of adventitious roots is clearly able to feed itself, and may become separated from the rest (*e.g.* by decay of the connecting shoot) and live an independent life. Increase in numbers in this manner is called **vegetative propagation.**

The abundant development of adventitious roots close to the leaves further obviates all need for additional conducting machinery, and the support of the soil renders new mechanical tissue equally unnecessary, so that plants without the means of secondary thickening find special advantages in the creeping habit.

The greatest danger which threatens the restriction of leaves to the surface of the soil is that of overshadowing by neighbouring foliage at a higher level; but the resulting etiolated condition, marked by the elongation of stem-internodes and leaf-stalks which follows such overshadowing, obviously provides a remedy.

Creeping stems.—One of the simplest examples of creeping stems is found in moneywort or creeping Jenny (Fig. 128). The soft *monopodial* stem keeps close to the ground, and the paired leaves, as well as the solitary yellow flowers which grow in their axils in June and July, have but short, weak stalks. Adventitious roots grow out in tufts at the nodes and penetrate the soil.

The ground ivy (Fig. 133) is slightly more specialised, for its thin square stem—a monopodium—produces a number of *erect* axillary branches, on which the blue flowers are borne along with

foliage leaves. The leaves on the *prostrate* stem and branches are also well raised to the light, for the stalks, stiffened by osmotic pressure of sap, are erect, and the stalks of leaves coming off at the sides and below turn so as to grow vertically upwards

FIG. 128.—Monopodial stem of Moneywort (Creeping Jenny).

like their fellows. The creeping stem and its side branches grow rapidly, putting out tufts of adventitious roots at the nodes, and in favourable circumstances soon cover the soil with a mosaic of leaves. The ground ivy is thus able to combine the advantages of the prostrate and erect habits.

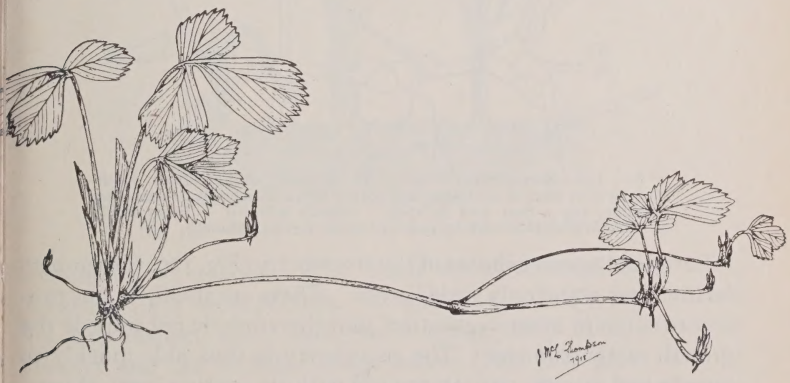


FIG. 129.—Strawberry Plant, bearing axillary buds developed as runners, with long internodes which may branch and root at their distal ends. (Reduced to half.) (After Thompson.)

Runners and stolons.—The strawberry, creeping buttercup, creeping cinquefoil, common bent grass, and most other plants which grow along the surface of the soil, differ from the creeping Jenny and ground ivy in having a *sympodial* stem.

The original tip does not grow indefinitely in a horizontal direction, but at length turns upwards to form a more or less erect shoot bearing foliage leaves and flowers. Presently a **branch** (called a runner or stolon) grows out from the axil of a leaf at the base of the erect shoot to straggle along the ground, and at some distance from its origin also turns up its tip to form more leaves and flowers, and sends down a tuft of adventitious roots into the soil. The process is repeated, so that the plant spreads in all directions.

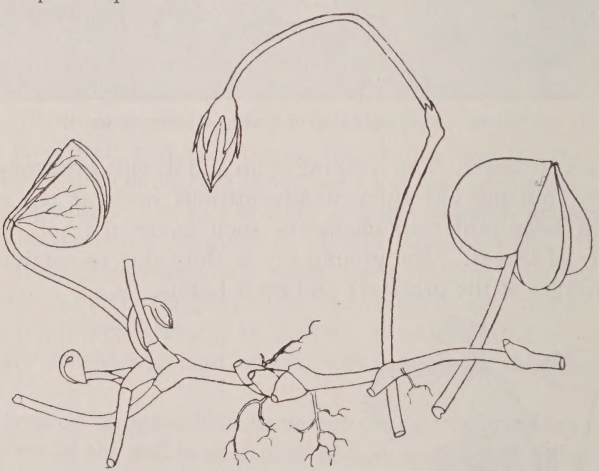


FIG. 130.—Monopodial rhizome of Wood Sorrel, with leaf-buds, flower-bud, swollen bases of old leaves, and roots; also a detached leaf in the sleep position, and a fruit with its stalk. Slightly enlarged. (From Miall's *House, Garden and Field*, by courtesy of Mr. Edward Arnold.)

Between the erect shoots of the strawberry (Fig. 129) the runners bear no roots, and only scale leaves. These are small, do not project to catch in other vegetation, and therefore do not impede the growth of the runners. The strawberry is thus able quickly to invade and occupy vacant ground with its rooting erect shoots, and when at length the scaly internodes wither, the new shoots grow independently. The formation of runners is thus an efficient means of vegetative propagation (p. 194).

Brambles, when unable to climb, form long, arched leafy shoots which may root at the tip on reaching the ground, and in all respects act as runners. Indeed, the behaviour of stems and

runners creeping on the surface of the soil suggests that of climbers which have failed to find a support. Twining and tendril climbers, however, do not normally produce adventitious roots, even when for lack of support they trail on the ground.

Rhizomes. — A stem growing horizontally *under* the soil is called a rhizome. Like prostrate stems on the surface, rhizomes are of varying grades of complexity. They are most

FIG. 131.—Sympodial rhizome of Sand Sedge. (After Figuier.)

commonly sympodial. The wood sorrel rhizome (Fig. 130), however, is a *monopodium*. It does not give off erect shoots (in this respect being like the creeping-Jenny stem), but the flowers and the ternate foliage leaves (Fig. 180) grow directly on it, and emerge separately from the soil. Small scale leaves also grow on the stem.

The sand sedge (Fig. 131) affords an excellent example of a sympodial rhizome. It is thin, and clothed with adventitious roots, but all its leaves are scale leaves, except in the terminal bud. This being pointed and horny makes its way

easily through the sand, and in due course turns upwards to form the erect shoot, bearing leaves and flowers, which alone appears above the surface. In the meantime a branch develops from the axil of a scale-leaf where the end of the stem bends upwards, and grows forward in the line of the original stem, presently to become erect in its turn and be succeeded by a branch of itself. The rhizome thus appears as continuous as that of wood sorrel, but is evidently a succession of branches.

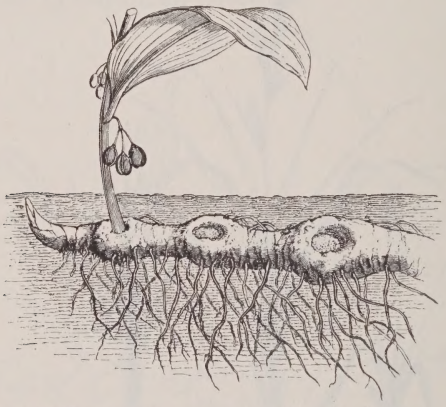


FIG. 132.—Swollen sympodial rhizome of Solomon's Seal, showing base of erect shoot of current year (with one leaf and flowers), bud for next year's erect shoot, and scars of erect shoots of two previous years. (After Figuier.)

The lily of the valley (Fig. 302), wood anemone (Fig. 243), white deadnettle, mint, and many other plants have rhizomes of essentially similar habit. In the Solomon's seal rhizome (which is conspicuously swollen with stored food—largely grape sugar) the positions of the erect shoots of previous years are marked by seal-like scars (Fig. 132).

Couch grass is a troublesome weed which spreads by rhizomes with short branches, difficult to eradicate from the soil. Such short underground shoots, arising either from the underground base of an erect stem or from a rhizome, or exceptionally from roots, and turning upwards to pierce the soil close to their origin, are called **suckers.** They are well seen in couch grass, wood sage, white deadnettle, mint, yarrow, dog-rose, apple, hazel, poplar, etc. The formation of *short* rhizomes and suckers naturally gives rise to a dense mat, bearing a clump of erect

shoots. When the rhizomes are *long* and straight, the erect shoots are in straight lines.

Creeping and erect habits compared.—It will be noticed that in horizontal stems, whether growing above or below ground, we can distinguish, as in most animals, between front and hind ends, between right and left sides, and between upper (dorsal) and lower (ventral) surfaces. Since, as the front end grows forwards, the hinder end commonly withers and dies, such a plant travels steadily about from place to place—also in a manner suggesting that of an animal—and is thus able to test the various possibilities which the neighbourhood affords of better water supplies and other advantages. In these respects the plant with an ordinary erect stem is different. It is exposed on all sides to almost equal conditions of light and temperature, of air and moisture; and it naturally tends to develop to an equal extent on all sides of the vertical axis: in other words, its symmetry tends to be *radial*. As a consequence it moves but little, if at all, from the spot in which it grew up from the seed. As we have just seen, many plants combine the creeping and erect habits.

Rosette plants and "root stocks."—In the dandelion, daisy, primrose, plantain, and many other plants, especially common in short turf, etc., and on rockeries, the stem is erect, but remains very short because its internodes lack the normal power to elongate. Such a short, vertical stem is, unfortunately, called a **root stock**. Its leaves spread out to form a rosette, which often lies flat on the ground. As the young upper leaves expand in turn from the central bud, they naturally overshadow those below. The stalks of the lower leaves, thus etiolated, respond by lengthening and so pushing their blades more to the outside of the rosette, where they are not overshadowed. The result is that the leaves so arrange themselves (Fig. 133) that very few chinks are left through which light from above can pass unintercepted. The plant thus "stakes out a claim," appropriating to its own use all the area covered by the rosette of leaves, protecting itself from excessive transpiration (p. 84), and incidentally preventing its share of soil from drying so rapidly by evaporation.

The rosette does not increase in size to an indefinite extent; for the lowest and oldest leaves die off as the young leaves

expand above. The continued activity of the terminal bud in the centre of the rosette would in time produce a stem raised distinctly above the level of the ground, were it not that certain roots—after growing specially long, and getting a firm grip of the soil—shorten, and drag the stem back into the ground to the extent required to keep it in its original position. Such roots are called **contractile roots**; they may be recognised by

Photo. Henry Irving.

FIG. 133.—Leaf-mosaic of Ground Ivy, and rosette of Ploughman's Spikenard (a biennial) at the end of its first year.

the transverse wrinkling of their surfaces. Not only "root stocks," but also bulbs, rhizomes and underground stems in general (pp. 211 and 217) are thus pulled to a lower level in the soil when necessary.

The dandelion (Fig. 134) and spear thistle have long, thick tap roots; most rosette plants have adventitious roots after the seedling stage.

Interesting differences are to be seen when such plants (which in open ground form flat rosettes) grow among long grasses which overshadow them. Again etiolation works its own cure, for the

leaves grow long and erect, and so compete successfully with the surrounding vegetation.

The daisy and the houseleek are examples of rosette plants in which vegetative propagation takes place by means of short runners called **offsets**, which are formed in the axils of the leaves.

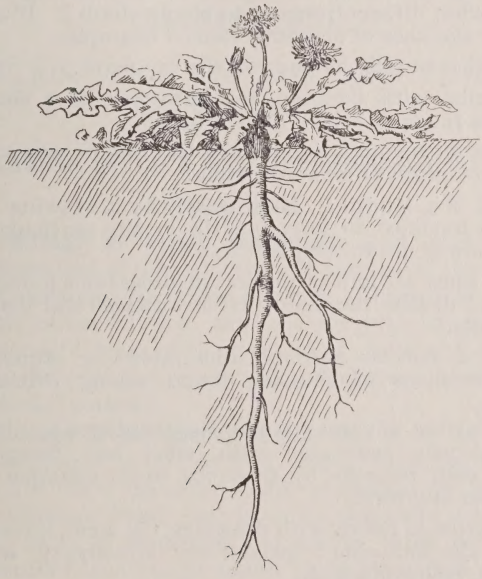


FIG. 134.—Habit of growth of Dandelion. (After Bailey.)

Each offset takes root and its tip turns up to form a new rosette. The " cushion " habit seen so often in rockery plants is a result of the formation of offsets.

It will be remembered that leaves springing from under ground stems (which by people ignorant of botany are usually regarded as roots) are called *radical* * leaves, to distinguish them from leaves growing on what is obviously the stem, which are referred to as *cauline* † leaves.

* Lat. *radix*, a root. † Lat. *caulis*, a stem.

EXERCISES XI.

1. Describe two examples of native climbing plants. Where do they grow ? and what is their winter condition ? (J.M.B. Hr. Sch. Cert.)

2. Of what advantage to a plant is the climbing habit ? By means of what different organs do plants climb ? Illustrate your answer by sketches of definitely named examples. (O.S.)

3. Describe as fully as you can the ivy plant. (Prel. Cert.)

4. Describe with sketches, the behaviour of a shoot of wild rose, (*a*) on the open heath, (*b*) in a hedge.

5. Write an account, and give a drawing, of any named plant climbing by means of a twining stem.

6. What is a tendril ? Show clearly by a drawing what parts have been modified to form tendrils in any particular case, and how they are of use to the plant named.

7. Give some account of the leaf modifications found in the pea family, and discuss the associated advantages and disadvantages to the plants.

8. Give a concise account, illustrated by sketches, of the different methods of climbing found among British climbing plants. (L.M.)

9. Discuss the advantages and disadvantages to plants, which are respectively associated with erect and creeping stems. Illustrate your remarks by reference to an example of each of these habits of growth.

10. Describe in detail, with drawings, the stem, leaves and roots of *one* of the following : ground ivy, strawberry, wood sorrel, sand sedge, Solomon's seal.

11. How do the following resemble and differ from each other : runner, rhizome, sucker, offset ? Mention two examples of each.

12. Describe, with explanatory drawings, the characteristic features of stems, leaves and roots which enable daisy, dandelion and plantain to live successfully in grass lawns. How are such weeds modified by growth among long grasses ?

13. In the field how do you distinguish a *root* from a *rhizome* ? Give drawings illustrating the distinctions. (L.L.A.)

14. Make labelled drawings of specimen N and describe it concisely. What is the value of this organ to the plant ?
[N = *Convolvulus arvensis* (rhizome and shoot).] (C.J.)

15. Distinguish between any two of the following pairs : (*a*) Fruit and seed, (*b*) sympodial and monopodial branching, (*c*) root and rhizome, (*d*) phyllode and cladode (phylloclade), (*e*) lateral branches from a main root and adventitious roots. Illustrate your answers by examples and diagrams. (C.S.)

CHAPTER XII.

PERENNATION, FOOD STORAGE, AND VEGETATIVE PROPAGATION.

24. DURATION OF LIFE AND THE STORAGE OF FOOD.

PRACTICAL.

1. Food storage in woody perennials.—Cut through twigs of various trees and shrubs at different seasons of the year, and wet the cut surfaces with iodine solution. If possible treat thin sections with iodine solution, and examine with the microscope. Make notes and sketches of the position of any starch which you may detect. Do you find any evidence that stored starch is used at any particular season ?

2. Food storage in herbaceous perennials.—Test the following swollen underground parts for food stores : (i) tuber of potato, rhizome of iris, corm (so-called bulb) of crocus, *for starch* ; (ii) rhizome of Solomon's seal, bulb of onion, *for grape sugar* (p. 15) ; (iii) swollen roots of dandelion and dahlia, tuber of Jerusalem artichoke, bulb of bluebell, *for inulin* (by soaking thin sections in alcohol for a week or less, when the inulin separates as small shining glassy particles easily seen with the microscope).

3. Food storage in biennials.—Test for grape sugar the " root " of carrot at the end of its first season. Let a carrot remain in the ground a second season, and when it has " run to seed " pull it up and examine the root. Try to find out the nature of the food materials present in " roots " of radish, turnip, beet and mullein taken up in the first autumn of their growth.

Examine young plants of the above biennials at different stages during the first year's growth, and try to discover if the swollen part is wholly root.

4. Food storage in seeds.—Revise the tests (Chap. I.) for food materials present in seeds.

Interruption of growth by seed production.—In the higher plants, the climax of life—for which growth and nutrition have been merely the preparation—is flowering and the formation of healthy seeds, by means of which individuals of *a new generation* are given a start in life. The actual work of the flower, resulting in seed formation, will be studied in Part II.; we are concerned here with certain special preparations made for this work.

The formation of flowers and seeds is always a great drain on a plant, for it involves the use of large amounts of food and energy in a very short time. Thus reproduction is only possible when the plant has a certain balance of food in reserve. The sudden call on its resources is often so exhausting that after this supreme effort it dies, leaving its race to be continued by the embryos in the seeds it has succeeded in producing. In other cases, where the stock of food laid up is more than that immediately required for seed production, the plant may survive from season to season, alternating vegetative periods of "saving" with reproductive periods of lavish expenditure. We may therefore consider that in this respect flowering plants fall into two groups: (*a*) those which form seed once and then die, (*b*) those which form seed more than once.

Interruption of growth by unfavourable seasons.—In countries like Great Britain, however, where the seasons differ so much in suitability for plant activity, a second factor interrupts the continuity of growth; for once a year most of our flowering plants are compelled to a period of inactivity by the **cold of winter**, which interferes especially with the absorption of water by the roots (p. 137), though the soil may be quite damp. Plainly, free transpiration under these conditions would be highly dangerous. Most British flowering plants escape this great risk by discarding their transpiring organs (leaves and herbaceous stems) before winter (p. 86), and are therefore said to be *deciduous*. It must be remembered, however, that the organs discarded are precisely the organs on which the plant has relied for the manufacture of food, and that, therefore, a deciduous plant finds itself in spring without effective food-making machinery (leaves). The new leaves are, indeed, waiting in their buds, but they cannot unfold and begin work without being

supplied with food (p. 176). Such plants, therefore, cannot survive the winter unless they have stored up, before winter, sufficient food to keep them alive and to provide the building material needed to put their food-making machinery into working order in the spring—just as the embryo in a seed can only become a self-supporting plant by living, at the beginning of germination, on food stored in the seed.

In certain cases it is **lack of light**, rather than lack of available water, which periodically interrupts vegetative activity. Thus many woodland plants (*e.g.* wild hyacinth) are compelled to make the year's supply of food in a few weeks of spring, before photosynthesis is rendered too difficult for them by the shade cast by the foliage of the trees above.

Fig. 135.—Shepherd's Purse, a common ephemeral. ($\times \frac{1}{2}$.)

In "temperate" climates, therefore, plant growth is interrupted not only by periodic seed production, but also by the regular alternation of favourable and unfavourable seasons. For this reason it is convenient to classify the life-duration of plants somewhat more fully than in the manner suggested on p. 204.

Plants which produce seed only once.—Chickweed, shepherd's purse, groundsel, annual meadow grass, and various other very common plants complete the whole of their life-history in a few weeks. The individual springs up from a seed, and by the activity of its leaves, root, and stem, soon accumulates enough (but not more than enough) food for the effort of reproduction; having seeded, it dies at once. The new seeds promptly germinate, and the plants of the new generation behave as their parents did, and come as quickly to the end of their lives. In this way such plants go through several generations during the year; they are called **ephemerals**. The life of an ephemeral may be prolonged by removing the flower buds as

fast as they are formed, and thus preventing stored food from being used for the ripening of seeds.

Annuals are plants which in one year pass through one complete generation and then die. Usually the seeds germinate in the spring, after having lain in the ground through the winter, and the resulting plants, having shed their own seeds, perish before the next winter. With such plants it is only the seed stage which survives the winter.

Fig. 136.—Plant of Carrot at the close of the first year's growth. (After Nicholson.)

Other annuals, common in hotter and drier climates, find summer a more trying time than winter, and therefore germinate in the autumn and die immediately after seeding in the following spring. The seeds alone of such plants survive the summer, while the young plants spend the winter in the "rosette" condition and thus secure a certain amount of protection (p. 84). Not many wild British annuals behave in this way, but wheat sown in autumn is an example of a cultivated annual plant of this kind; and seeds of annuals (*e.g.* poppy, corn-flower) which in the wild state germinate in the spring, are often planted by gardeners in autumn for early flowering next spring.

Biennials are plants which, in Britain, germinate in the spring and devote the first season entirely to the production of food, and the second season to the production of seeds, after which they die at once. The surplus of food made in the first year is stored in underground organs through the winter, a season when the plant is in the "rosette" stage (Fig. 133), the stem remaining short (a "root

stock"). In the second year the stem elongates and produces flowers and seeds, the stored food being used up in this final part of the plant's life-work. Thus the so-called "root" of a carrot—which in reality consists chiefly of the swollen hypocotyl (p. 31)—is thick and conical at the end of the plant's first season (Fig. 136), but shrivels up during the second, as its contained food is drawn off to supply the flowers and seeds. The globular part of a turnip, or of a mangel, similarly, is swollen hypocotyl. If prevented from flowering, or if living under conditions specially favourable for food production, a biennial may survive for more than two seasons (*e.g.* foxglove). On the other hand, it may flower and die at the end of the first season (and thus become an annual) if unable to store food easily. Common biennials are foxglove (when wild), mullein, burdock, spear thistle, carrot, parsnip, turnip, swede, radish, mangel, and beet.

Perennials are plants which live for more than two years. Some of them flower and seed only once, perhaps after many years of preparation, and then die. There is no British example of this habit, but a remarkable instance is the American aloe (belonging to the family Amaryllidaceae (p. 413), which may live for a century before flowering, and then dies exhausted by the effort of ripening the seeds. It is evident that ephemerals, annuals, biennials, and those perennials which seed only once, differ merely in the length of the preparation made for the single great effort of reproduction.

Plants which produce seed more than once are obviously in a different category. They are all **perennials.** They agree in possessing, after seeding, a balance of unused food, which is sufficient to enable the plant to resume growth and food-making after the interruption.

Food reserves.—From the foregoing, the vital importance to a flowering plant of making, and storing, food in excess of its immediate needs is clear. Such food may accumulate in any parenchymatous tissue (p. 96); consequently, as will be seen in the next section, leaves, stems and roots are all used as storage organs by various plants, and for this reason often assume greatly distorted shapes. **In trees and shrubs** the tissues of both stem and root are used for storage: abundance of starch

accumulating in the medullary rays, the cortex and the parenchyma of the wood, in readiness for the great demands of spring (Expt. 1, p. 203). **Herbaceous plants** usually store their surplus wealth in underground parts (swollen roots, stems or leaves), which are protected by their position from many dangers (frost, being eaten by animals, etc.).

The nature of the stored food also varies very much. *Protein* (p. 18) is to be found in all storage organs, and is especially abundant in seeds. *Fats and oils* are also commoner in seeds (*e.g.* sunflower, linseed, Brazil nut) than elsewhere. Several forms of *carbohydrates* occur—starch, cellulose, inulin, gum, grape sugar, cane sugar—which resemble each other so closely in composition that in the plant they readily change from one to another by the addition or abstraction of a molecule of water (p. 21). It should be remembered, however, that foods cannot pass from one part of the plant to another except in solution, and that, therefore, before a store of insoluble food like starch can be drawn upon to supply another part of the plant, it must be turned into a soluble form. Thus insoluble starch is converted when necessary into a soluble sugar (maltose) by the action of an enzyme called *diastase*. Conversely, wherever starch occurs in a plant, it has been formed *on the spot* (by the action of plastids), from sugar in solution in the cell sap.

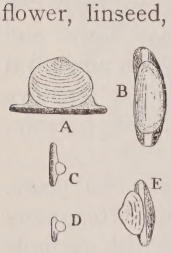


FIG. 137.—Leukoplastids from *Phajus* (× 180.) (After Strasburger.)

We may illustrate these changes by following in imagination the probable transformations (p. 72) by which a particle of starch comes to be present in, say, a root (Fig. 83): (*a*) In the leaf, *carbon dioxide* from the air reacted with *water* from the soil to form *formaldehyde*; this "condensed" to form *sugar*, which by the action of chloroplastids became *starch*; this starch was turned into *sugar* again by the enzyme diastase. (*b*) This sugar travelled in solution from the leaf, through the leaf stalk, stem and root, to the storage region (*e.g.* cortex) of the root. (*c*) Here the sugar was re-converted into *starch* by the action of leukoplastids. Should this food be needed later, to supply material for, say, the sprouting of a leaf bud or flower bud, it will be converted once more into soluble sugar by the enzyme diastase, and will travel as sugar through the young wood to the centres of activity.

25. VEGETATIVE PROPAGATION AND THE STORAGE OF FOOD.

PRACTICAL.

1. Swollen adventitious roots.—Take up a plant of lesser celandine in early spring, and study the roots. Notice that some are fibrous, some club-shaped and others potato-shaped (tuberous). Test some swollen roots for starch. Look for others which are beginning to sprout, and observe the bud at one end. Look in the axils of the lower foliage leaves and try to see the early stages of the tuberous roots.

Compare the swollen roots of dahlia and early purple orchis.

2. Swollen rhizomes.—Compare the condition of the front and hinder ends of rhizomes of Solomon's seal, and look for cases of one rhizome separating into two. What is the cause of the separation ?

3. Tubers.—Dig up and examine the underground parts of perennial sunflower, Jerusalem artichoke, and potato. Does the part swollen at the end to form the tuber consist of a root or of a stem-branch ? Trace it to its origin to see if it arises in the axil of a scale leaf or of a foliage leaf. Does it also bear scale leaves ? Find the axillary and terminal buds on each tuber. Plant a tuber in warm, moist earth, and examine and draw it at intervals. What is the nature of the "eyes" of the potato ? By what means (apart from seed production) would these plants increase in numbers if left to themselves in the soil ? Test (*a*) a "new" potato, (*b*) an "old" potato for both starch and grape sugar. Examine potato plants for occasional tubers in the axils of leaves above ground.

4. Corms.—(*a*) In early spring look in hedges for the arrow-head-shaped (sagittate) leaves of *wild arum*.* Dig up several plants ; notice the swelling (corm) from which the erect shoot arises, and behind it the remains of the corm of last season (and possibly of the season before last). How many vertical shoots arise from one corm ? Dig up other plants in the summer and autumn, and find out (i) whether the stem is sympodial or monopodial, (ii) by what means (apart from seeding) the plant increases in numbers.

* One of the three British monocotyledons with net-veined leaves. The others are the black bryony or *Tamus* (p. 186) and Herb Paris (p. 413).

(*b*) Examine *crocus* corms (called crocus " bulbs " by seedsmen) in early winter. Notice the scar of last spring's flowering shoot, one or more buds at the top, and a withered disk (easily detached) at the base of each corm. Peel off the brittle scales or " tunics," noticing the circular scar left by each, and look for buds in their axils. Cut another corm through lengthwise so as to bisect the largest bud, and draw the section. Dissect a whole bud with needles and notice (i) the thin, outer scale leaves, (ii) the young foliage leaves, (iii) the flower.

Plant the remaining corms, and take up and examine one or more at intervals (*e.g.* in midwinter, when the plant is in flower, in summer, and when the leaves are withering). In this way find out (i) where the roots grow, (ii) what part swells to form a new corm, (iii) the nature of the scaly tunics, (iv) the place of origin of the new buds. Notice at each stage what remains of previous seasons' growth are still present, and what provision is being made for the future. How do the plants increase in number, apart from seed production ? How are the new corms prevented from growing out of the ground, although they grow on the top of the old corms ? Try to frame a definition of a corm.

5. Bulbs.—(*a*) Examine a *snowdrop* bulb, as supplied by florists in autumn, and take off the parts in turn. Note the three dry scales (the remains of the three leaves of the season before last), then three fleshy scales *with withered tops* (the remains of the leaves of last season), and lastly the bud for next spring—consisting of three young leaves round a flower. Look for buds in the axil of the outer scale of each set of three. What provision for vegetative propagation does the bulb show ? Observe the short, flattened stem left after removal of the leaves. How do you know it is a stem ?

Make longitudinal and transverse sections of other snowdrop bulbs, and draw them, dating each set of three leaves with the year in which they were, or would have been, green.

Plant other bulbs, and take them up at different stages to see how the various parts are behaving. Keep dated notes of the observations. Are all the leaves of snowdrop " radical " ?

(*b*) Compare the bulb of snowdrop with those of single *daffodil* (or narcissus) and *hyacinth*, and notice that some of their fleshy scales are not the enlarged bases of former foliage leaves, since the upper ends show no sign of scars or withering. These bulbs, therefore, contain two kinds of fleshy scales. In summer take up bulbs and notice the thickening of the bases of the foliage leaves.

Look for wild hyacinth seedlings of various ages, and observe the *contractile roots* by which the young plants are gradually dragged down from the surface to a depth of about a foot. Look for both kinds of fleshy scales in *onion* bulbs.

(*c*) Study the bulbs and flowering plants of *tulip*. Are the foliage leaves cauline or radical? Are any of the fleshy bulb scales withered at the top? Explain the connection between the two facts.

Carefully remove the flowering shoot from a tulip bulb before planting at the beginning of winter, and at the end of the season observe the number of buds formed in the new bulb.

6. Adventitious buds.—Slit thick scales of lily or hyacinth bulbs, plant the pieces in earth and keep warm and moist. Notice the formation of small bulbs along the edges of the slits.

Vegetative propagation.—The increase in numbers which results from the separation and independent growth of some vegetative organ of a plant from the rest is called vegetative propagation. It must be distinguished very carefully from true reproduction, that is, the increase in numbers which, in flowering plants, is brought about by the formation and germination of seeds. An example will explain the most obvious difference between the two methods. Suppose a plant produces ten seeds, which germinate successfully. The resulting ten plants belong to a new generation *; they are new individuals, and are the offspring of the parent plant which produced the seeds. This is very different from the state of affairs resulting from the outgrowth and rooting of ten runners of a strawberry. The ten "new plants," left when the connecting branches decay, are not new individuals, and do not belong to a new generation; they are merely separated *parts of the same individual*, just as the branches of an oak tree are parts of the same individual. They are not the offspring of the plant on which the runners grew; nor is this plant their parent.

Among the **advantages of vegetative propagation** are: (1) it multiplies the individual's chances of survival, by freeing it from dependence on a single line of supply of soil water to the leaves; (2) it is less exhausting than reproduction by seeds.

* At the origin of a new generation, certain important changes in the constitution of the cell nucleus always occur.

Artificial cultivation.—In the artificial cultivation of plants, vegetative propagation is practised extensively to perpetuate desirable qualities of flowers, fruit or other parts. Plants raised from seeds, even of the same parent, tend to vary greatly in many respects, and cannot be trusted to be stronger or larger, or to produce finer flowers or fruit, merely because their parents were better than the average (p. 486). Thus, a seed from even the most valuable strain of apple will grow into a crab-apple tree, bearing crab apples only; the choice qualities of any particular kind of apple are passed on not by sowing the seed of that apple, but by grafting a bud from the branch bearing it on to a crab-apple tree (called the *stock*). The tissues of the bud unite with the tissues of the stock, and the bud grows into a shoot (called the *scion*) which will branch and ultimately bear fruit of the desired kind (Fig. 138). Similarly, to propagate the excellent varieties of potato which have been obtained by repeated selection of the best, the farmer does not plant the true seeds from the berries which succeed the flowers; he plants tubers, which, although they are known as "seed potatoes," are really the swollen ends of underground branches. Again, gardeners propagate carnations, currants, etc., by "layering," *i.e.* pegging the stems down to the ground until they root at the nodes. Cultivated roses are propagated by cuttings or slips—branches cut off and planted after they have been induced to form adventitious roots—or by grafts on a stock of wild rose.

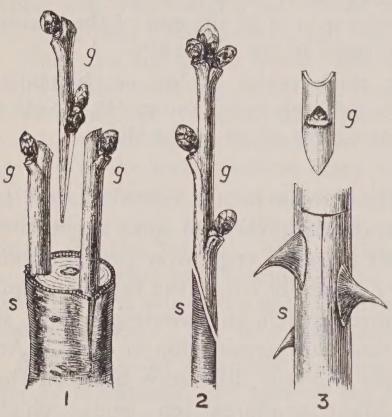


FIG. 138.—Different modes of grafting. 1. Crown grafting. 2. Splice grafting. 3. Bud grafting. *s*, stock; *g*, scion. (After Noll.)

Food storage and vegetative propagation.—In these and other cases of vegetative propagation **the starting point of the new shoot is a bud**, which, as we know, is a "telescoped" stem bearing young leaves. If this can form roots, or in some other

way (*e.g.* by union with the living tissues of another plant, as by grafting or parasitism) be assured of a supply of soil water, it is in a position to develop into a plant like that from which it separated. The development of such a bud will be especially rapid if it can draw upon a store of previously prepared organic food.

From these considerations it will be understood why vegetative propagation takes place most freely (1) in plants the stem branches of which can easily send adventitious roots into the soil, and (2) in plants which can make and store large quantities of reserve food.

We have already (p. 196) had simple examples of vegetative propagation where prostrate branches—in some cases above, in others below, the surface of the soil—without any marked storage of food become separated, as it were accidentally, by decay of the parts behind. We have also met with several examples of food reserves, which were evidently of use merely to provide material for resumption of growth after a period of enforced rest, and had nothing to do with vegetative propagation. We must now consider cases where food storage is definitely associated with vegetative propagation.

Swollen adventitious roots.—In the **lesser celandine** (the earliest of the buttercups to flower), vegetative propagation takes place abundantly by means of small swollen roots, in shape somewhat like minute potatoes, and therefore called tuberous (*i.e.* tuber-like) roots (Fig. 139). The mode of origin of the tuberous roots is interesting. In spring, when the plant is making food in abundance, large numbers of buds appear in the axils of the sheathing leaves. Some of these buds grow out to form ordinary branches, bearing leaves and flowers ; the other buds (especially those near the base of the stem) immediately form each an adventitious root, perhaps $\frac{1}{4}$ of an inch in length, which by the accumulation of food in it, becomes swollen to such an extent that the original bud at its upper end is scarcely noticeable. Such a body is obviously fitted admirably for vegetative propagation : its bud is ready at any time to grow out quickly at the expense of the adjoining food store to form a leafy stem, which can itself put out adventitious roots for the absorption

of water at need. Numerous tuberous roots of this kind (formed the previous season) are to be found (together with new fibrous roots at a higher level employed in the absorption of water) at the base of the stem of any plant of lesser celandine in early spring. They are easily detached by rain—

FIG. 139.—Lesser Celandine (*Ranunculus ficaria*) in March. *t.r.*, tuberous roots; *f.r.*, fibrous roots; *B*, axillary bulbil; *sh.*, new shoot growing from bud at end of a tuberous root. (After a photograph by Henry Irving.) ($\times \frac{1}{2}$.)

giving rise to occasional stories of "showers of potatoes"—and washed to some little distance, where they sprout as separate plants.

The **early purple orchis** annually forms a similar tuberous root at the base of an axillary bud (in addition to its ordinary fibrous roots), which produces the shoot of the following year. Thus a plant examined in the summer would possess three tuberous roots: that at the bottom of the current year's shoot, the young one preparing for next year's shoot, and the old withered remains

of last year's. Sometimes two such tuberous roots are formed in one year, and in this case vegetative propagation results, since the number of the plants is increased.

The **dahlia** is another plant which stores food in swollen adventitious roots, each with a bud at the top which sprouts later to form a "new" plant.

Fig. 140.—Longitudinal section passing through the old and new tubers of an Orchis. (After Luerssen.)

Tubers.—A tuber is the swollen end of an underground stem branch. Various interesting stages of the modification are found. In the **potato** the tuber is globular or ovoid, and its "eyes"—each (except the terminal one) in the axil of a scale leaf—are not at first sight obviously buds. In the **Jerusalem artichoke** (Fig. 143) the tuber is club-shaped, and the nature of the scale leaves and buds on it is clear. In the **perennial sunflower** the terminal swelling of the underground branch is but slight. Potato tubers occasionally grow in the axils of leaves above ground, and become green, with a bitter taste, unless etiolated by being "earthed-up" (p. 67).

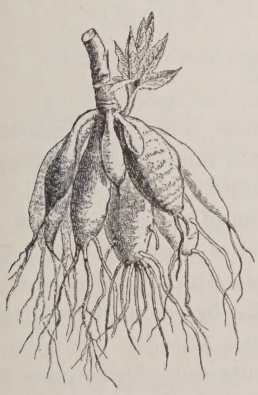


Fig. 141.—Tuberous roots of the Dahlia. (After Figuier.)

Fig. 142.—Part of a Potato Plant, showing the old tuber (dark), and several new ones. (Strasburger.)

When a tuber is allowed to sprout, a shoot—bearing leaves and branches and in due course other tubers, as well as adventitious roots—develops from each "eye," and when the

old tuber ultimately rots away, the new shoots behave as independent plants.

Corms.—What are known commonly as **crocus** "bulbs," but botanically as crocus corms, in the resting condition as sold by seedsmen, resemble tubers in consisting of solid rounded bodies

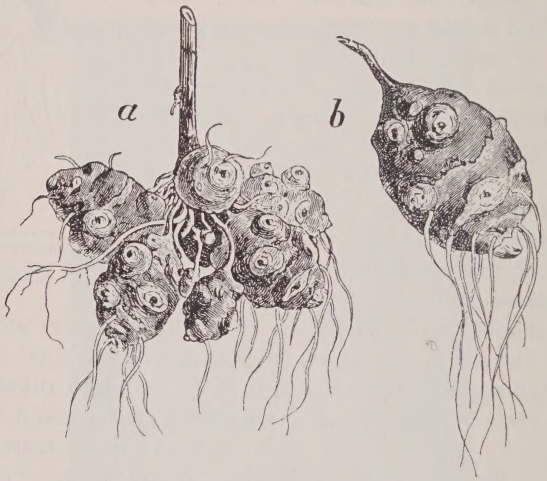


FIG. 143.—Jerusalem Artichoke. Stem-tubers, producing slender roots. (After Vilmorin.)

bearing buds (Fig. 144). A crocus corm, however, is neither a tuber nor a bulb. It is clothed with a number of overlapping "tunics," which are the withered remains of former leaves. Buds usually occur in the axils of some of these old leaves, and a terminal bud is prominent at the top of the corm. In a large bud the flower and young leaves may already be found. At the bottom of the corm may often be seen the flattened shrivelled remains of last year's corm.

When such a corm is planted, it puts out adventitious roots below, which supply it with water, and the terminal bud * develops at the expense of the stored food, its long flower growing out at the top of a short stem in early spring, and being kept

* Usually, not only the terminal bud, but also one or more axillary buds, will develop.

erect by sheathing scales wrapping round both the soft flower-tube and the narrow green foliage leaves which quickly make their appearance from the same bud (Fig. 305). Both scale leaves and foliage leaves are " radical " leaves, being inserted on the corm ; and their bases completely and closely encircle the base of the flowering stem. The foliage leaves continue active after the flower has faded, and the surplus food they make accumulates at the base of the flowering stem to form a new corm.

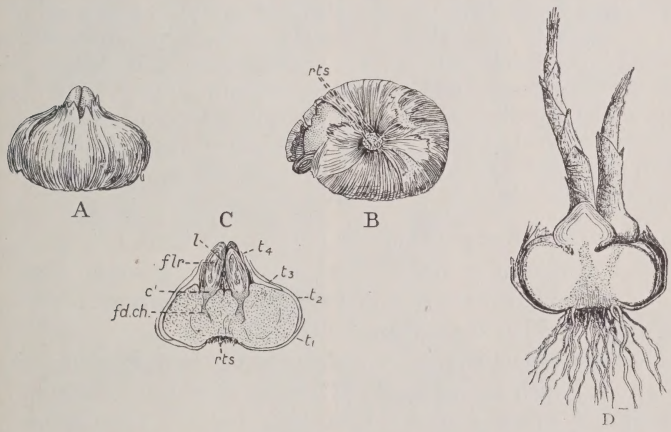


FIG. 144.—Crocus corm, seen from the side, from below, and in longitudinal section. (× ½.) A-C show the winter resting stage, D the resumption of growth in spring. The flowering stage is shown in Fig. 305. *c'*, base of bud, beginning to swell in D to form next year's corm ; *fd.ch.*, channels for passage of food from corm to bud ; *flr*, flower bud ; *l*, young leaves ; *rts*, early stage of new adventitious roots ; t_1-t_4, tunics. (D, after Figuier.)

In the meantime buds for future corms have appeared in the axils of some of the leaves, especially those nearest the flowering stem. Since each new corm is formed at the base of an *axillary* shoot of the old corm, the method of branching of the crocus is sympodial. The old corm has shrunk by this time to form a soft brown or black mass below the new one, which naturally is at a higher level. Soon, however, one or two thick adventitious roots grow out from the base of the new corm, get a firm grip of the soil by means of their root hairs, and then *contract*, thus pulling down the new corm to the former level of the old one. The contractile roots then shrivel.

When sufficient food has accumulated, the foliage leaves also wither and are shed, their thin dried bases together with those of some of the old scale-leaves forming "tunics" round the corm, and the plant enters once more on the resting winter condition. If more than one bud of a corm develops to form a new corm, vegetative propagation results.

A corm may thus be defined as the swollen underground base of a previously erect stem.

The **cuckoo pint** (wild arum) also perennates by means of a corm. In this case the old corms last—in a more or less shrunken condition—for several seasons, each attached to the base of its successor, so that the underground part of the plant somewhat suggests a short, stumpy rhizome of the type found in Solomon's seal (p. 198). Other well-known examples of corms are those of the garden plant Montbretia, the weed onion-couch grass, and the "bulbous" buttercup.

Bulbs.—The storage of reserve food in leaf bases is seen in its simplest condition in wood sorrel, in which the lower ends of the leaves become swollen and persist on the rhizome after the rest of the leaf has disappeared (Fig. 130).

A **bulb** is an underground *bud*, some of the leaves of which are swollen with stored food. These swollen leaves may be of two kinds. In some cases they are the bases of former foliage leaves, the upper parts of which have been shed. In such cases the upper edges of the swollen scales are brown and show either signs of withering, or scars where the upper portions broke off. The **snowdrop** has a bulb of this kind. Each season three "radical" leaves—viz. an outer sheathing leaf and two foliage leaves—come above the ground, and the excess of food made during the vegetative period accumulates in their bases. The upper parts of the leaves are shed when the season's work of photosynthesis is finished, and their swollen bases form the bulk of the resting bulb. Outside these are the bases—now thin and dry—of the three leaves of the previous season; while nearer the middle is next season's bud, containing three leaves and a flower shoot in the axil of the innermost. All these nine leaves and the flower stalk grow on a short flattened stem, the lower side of which puts out adventitious

roots. In the axil of the outermost of each set of three leaves there is usually a bud, which itself becomes a flowering bulb in due course. One such bulb naturally becomes detached each year by decay of the adjoining tissues, and brings about vegetative propagation.

On the other hand, the swollen scales (about four) of the **tulip** bulb—though morphologically leaves and bearing buds in

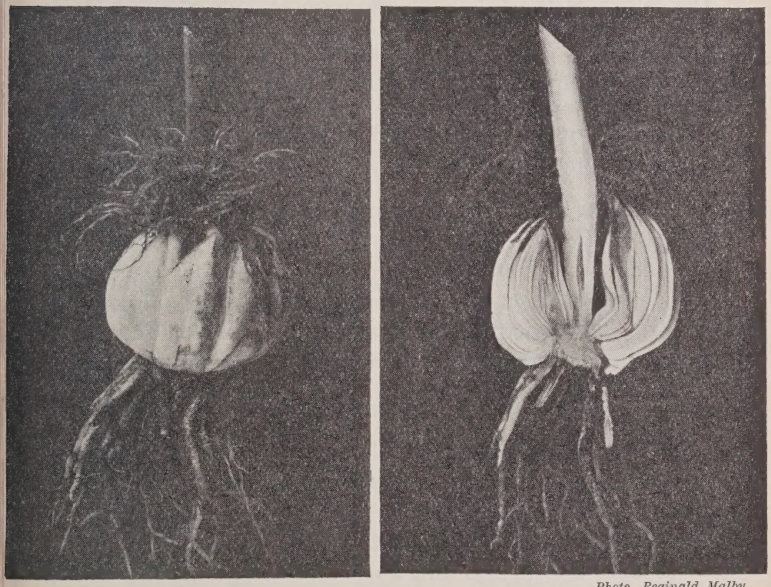


Photo. Reginald Malby.

FIG. 145.—Lily bulb entire and in longitudinal section. A new bulb is seen in the section on the left of the base of the flowering shoot.

their axils—are not the bases of foliage leaves, for they never come above ground. They act purely and simply as organs for the winter storage of food made by the previous season's foliage leaves. The foliage leaves of the tulip are all "cauline," being borne on the erect shoot which ends in a flower (Fig. 201). During the vegetative season, the surplus food made by these leaves accumulates in the scales of the underground buds growing in the axils of the bulb-scales, and these buds—the innermost of

which becomes especially large—are thereby converted into the bulbs for next season. The foliage leaves themselves, of course, perish entirely when the erect shoot bearing them is shed.

The bulbs of **daffodil, narcissi, white lily** and **hyacinth** contain both kinds of scales, some, with withered tips (Fig. 145), being the swollen bases of former foliage leaves, while others are swollen entire scale leaves which never come above ground.

The flower of the tulip and the inflorescence of the hyacinth represent the *tip* of the stem. It follows that the next year's main bulb is axillary and therefore a branch of its predecessor. In the snowdrop and narcissus, however, the "apex" of the flat stem develops indefinitely, producing each year new leaves and an *axillary* flower. The tulip and hyacinth are therefore sympodial, while the snowdrop and narcissus are monopodial.

Adventitious buds.—In the foregoing examples of vegetative propagation the increase in numbers is evidently associated with the abundance of the food supply; this stimulates the development of buds which in other circumstances would have remained dormant. The sprouting of dormant buds which follows the loss of terminal buds in the trimming of hedges and the pruning of fruit trees is another instance of response to an increase of food.

The most remarkable example, however, is the growth of buds irregularly on stems or even on roots and leaves, which occasionally takes place. Thus shoots may grow on the cut surface of a felled or pollarded tree, or on the root of poplars, dandelions, some thistles and docks. Buds giving rise to leafy branches grow regularly on the leaves of certain ferns, and will arise on a begonia leaf pegged down to the soil. Finally, a broken fleshy scale of a lily bulb will often form a row of active buds along the line of injury, each becoming a separate bulb. Such shoots as these, which do not originate in the usual manner, are called adventitious shoots.

EXERCISES XII.

1. Distinguish between an ephemeral and an annual. Mention the circumstances which affect the normal duration of a plant's life, and refer to named examples.

2. What is an annual? What are the advantages and disadvantages of the annual habit? Mention *four* common wild annual plants, and state the situations in which you have seen them growing. (O.S.)

3. Describe carefully the course of development and the changes which occur in a typical biennial such as the turnip or carrot, from the germination of the seed to the end of the first year's growth. What further changes occur if the plant is left in the ground for a second year? (J.M.B. Sch. Cert.)

4. Describe, with sketches, the root-system of the broad bean. In what respects do the root-systems of (1) the carrot and (2) the ivy differ from that of the broad bean? What is the significance of these differences? (L.M.)

5. Explain the botanical significance of (*a*) the transplanting of seedlings of perennials; (*b*) the removal of fading sweet peas, etc., when a longer flowering period is desired. (Part question, C.S.)

6. Give an account of some of the ways in which perennial plants are fitted for an existence through many seasons. What internal and external changes occur in the twigs of the sycamore or elm in the spring? (J.M.B. Matric.)

7. Make careful, annotated drawings to illustrate the structure of specimen B; and point out the features of botanical interest. (B = radish.) (C.S.)

8. In what different ways are British plants adapted to withstand winter conditions? Give examples.
Mention the special advantages of each adaptation to which you refer. (O.S.)

9. In what forms do the coltsfoot, dandelion and primrose persist through the winter? Illustrate your answer by drawings. (Prel. Cert.)

10. What are the principal methods by which plants survive from one year to another in a country where there is a regular alternation of seasons? State exactly how growth is resumed in the following year. (C.S.)

11. Give a concise account of the chief ways in which plants prepare for their winter rest. Carefully contrast the summer condition of two of the plants you mention with their state in winter, giving illustrative sketches. (L.M.)

12. What adaptations are found in herbaceous plants in relation to seasonal alteration in temperate climates. (L.L.A.)

13. How would you test for starch in a green leaf ? Account as fully as you can for the presence of starch in a potato tuber.

14. How do you account for the presence of starch in the non-green parts as well as in the green parts of plants ? State clearly how starch arises in the latter, and of what use it is to the plant. (J.M.B. Sch. Cert. and Matric.)

15. In which parts of a plant do you expect to find sugar ? How would you identify it ? What is its origin ? (Prel. Cert.)

16. Give an account of the characters which enable many herbaceous plants to be perennial. Which parts of such plants are used for the storage of food, and in what forms is the food material (*a*) stored, (*b*) moved from place to place ? (J.M.B. Matric.)

17. Plants lay down stores of food at certain stages in their life-histories. State briefly what parts of the plant body are commonly used as storage places. Illustrate your answer by quoting several examples. (C.J.)

18. Give an account of the chief reserve food materials occurring in plants. Where do they occur and how would you recognise them ? (J.M.B. Hr. Sch. Cert.)

19. What is the nature of the food-stuffs stored in a wheat grain ? In what part of the plant are these food-stuffs manufactured, and how are they conducted to the grain ? By what tests can they be recognised ? (L.M.)

20. Given a bulb of the tulip, describe exactly how you would proceed to ascertain

(*a*) the use to the bulb of the scaly covering ;
(*b*) the nature of the food material stored in the bulb.
(J.M.B. Sch. Cert. and Matric.)

21. What is the nature of the food reserves in the following :— (*a*) potato, (*b*) onion, (*c*) bean, (*d*) Brazil nut, (*e*) beetroot ? How would you show the presence of each kind of food material ?

22. What functions are generally performed by the roots of ordinary green plants ? What other functions may roots perform ?

23. Give an account of four different kinds of root systems you have met with in plants. Indicate any special function which is connected with their peculiarities.

24. How would you distinguish between a stem and a root ? Describe an example of (*a*) an underground stem and (*b*) an aerial root. (J.B.M. Nat. Hist. paper.)

25. Describe carefully the external features of *either* the lesser celandine, *or* the coltsfoot. Under what conditions does the one you select flourish ? What features does it possess that enable it to flower so early and to be so widely spread ? (J.M.B. Hr. Sch. Cert.)

26. Give an example of each of the following: a *succulent* stem, a *climbing* stem, an *underground* stem, a *hairy* stem, a *thorny* stem. Suggest the probable reason for the special form in each case. (J.M.B. Jun. Cert.)

27. Carefully examine specimen X and make explanatory drawings. Label the different parts drawn, and very briefly state their functions. [X = Tuber of artichoke (*Helianthus tuberosa*).] (C.S. Dec.)

28. Describe, with drawings, the appearance of a potato-tuber. What happens when a potato-tuber is planted and grows?

29. Describe *all* the differences to be observed between a potato allowed to sprout in the dark and one sprouted and grown in the light. How do you account for the differences observed? (J.M.B. Matric.)

30. What reasons can you suggest to account for any *three* of the following?—(*a*) The majority of trees native to Britain lose their leaves in winter. (*b*) A block of wood splits more easily in some directions than others. (*c*) Nearly all monocotyledons are herbs, and not shrubs or trees. (*d*) It is important that potato plants should be "earthed up." (*e*) The glass of greenhouses is often whitewashed in summer. (*f*) It is a usual practice to prune fruit trees. (C.S.)

31. Relate the life-history of a crocus plant. (J.M.B. Jun. Cert.)

32. Describe, with sketches, a crocus plant at two distinct stages of its life. How are the young corms produced? (Prel. Cert.)

33. Write notes on food storage in the potato, onion, carrot, and one wild perennial. (Cert.)

34. What are the characteristic differences between a bulb, a corm and a tuber? In what respects are they alike? Illustrate your answer by drawings. (Cert.)

35. Give sketches of the structure of a bulb and of a corm in the dormant condition and also after the growth of flowers and leaves. (L.M.)

36. Select one of the following:—crocus, white lily, Solomon's seal, horse chestnut shoot. Draw (with explanatory labels) the plant as it appears,

(*a*) in winter (including a longitudinal section of its bud),
(*b*) in spring or early summer. (O.S.)

37. Describe the parts and methods by which vegetative reproduction takes place in the following plants:—(*a*) the strawberry, (*b*) the potato, (*c*) the crocus, (*d*) the hyacinth. (J.M.B. Sch. Cert. and Matric.)

38. Describe the structure of *one* of the following:—tulip bulb, crocus corm, potato tuber; and illustrate your answers with labelled diagrams. (O.J.)

39. Illustrate, by means of annotated drawings *only*, the structure of specimen Y (Y = dormant bulb of narcissus). (C.S. Dec.)

40. Mention three plants which produce bulbs. Taking any one of them, explain clearly with diagrams what changes take place in a bulb during a period of twelve months. (C.J.)

41. Describe the form and arrangement of the roots in a tree, a creeping herb (*e.g.* mint or couch grass), and a bulbous plant. How is the arrangement correlated with the form of the plant ? and what advantages or otherwise do you consider each to possess? (J.M.B. Hr. Sch. Cert.)

42. What are the functions of an ordinary herbaceous stem ? Quote any examples with which you are familiar of plants in which the stem carries out other functions. (C.J.)

43. Describe carefully the onion or iris plant as it appears in November, and give an account of the changes which take place in it during the following twelve months. (J.M.B. Sch. Cert. and Matric.)

44. Describe the present condition of *one* of the following plants, and trace the changes that it undergoes between one winter and the next :—crocus, daffodil, gladiolus, iris, or Solomon's seal. (J.M.B. Sch. Cert.)

45. Describe *four* British plants which propagate themselves by vegetative means, and illustrate your answer with diagrams. Mention the usual habitat of each of the plants. (O.S.)

46. State clearly in what part of the plant stores of food materials are to be found in maize (or wheat), tulip, and crocus.

47. Explain in what form *five* of the following plants pass the winter : lesser celandine (*Ranunculus ficaria*), potato, snowdrop, cowslip, parsnip, frog's bit (*Hydrocharis*).

Point out in each case where the food supplies are stored that will be required for growth in the following spring. (J.M.B. Hr. Sch. Cert.)

48. Describe, with the aid of drawings, the structure of any bulb in winter. What remains from past seasons, and what provision for a future season, does it show ?

49. Draw a longitudinal section of the bulb of *either* a tulip *or* a narcissus, (*a*) at the time of planting in the autumn, (*b*) at the time of flowering in the spring.

Name the parts of your drawings. (O.S.)

50. Describe an example you have examined of a plant spreading by vegetative means. How does propagation occur in the case you select, and how does the plant spread to new localities ? (J.M.B. Hr. Sch. Cert.)

51. Describe by reference to definite examples three ways in which vegetative propagation of plants may be brought about. (J.M.B. Matric.)

52. What means of propagation do plants possess apart from the production of seeds ? What advantages has seed production over these methods ? (C.S.)

CHAPTER XIII.

SPECIAL METHODS OF NUTRITION.

26. PARASITIC FLOWERING PLANTS.

PRACTICAL.

1. Total parasites.—(*a*) Look in summer for the pink, thread-like coiling stems of *dodder* on nettles, clover, heather, gorse, flax, etc. Find out whether they have any connection with the ground. Notice the small suckers where the stems are in contact with those of the host. Does the dodder bear any green leaves ? Look for very small scale leaves on the stem. Observe the large number of seeds formed in the small, closely set pink flowers (July-Sept.).

(*b*) In June-Oct. look among clover, etc., for the upright shoots of *broomrape*, with brown flowers and small brown leaves. Trace the shoot into the soil and note the attachment of the tuberous underground portion to the roots of the clover.

2. Partial parasites.—In summer, cut out grassy sods, including plants of yellow rattle, eyebright, bartsia or cow-wheat,* and wash away the soil very carefully. Notice that the roots of the plants mentioned are attached here and there to the grass roots by small suckers. Do these plants have green foliage leaves ?

3. Mistletoe.—On what trees have you found mistletoe growing ? If possible, saw through the part of the tree branch to which the mistletoe stem is attached, and rub the cut surface smooth with glass paper. Make a drawing to show the manner of connection of the two plants.

Various ways of obtaining food.—Only green plants can build up organic foods for themselves, from the much simpler inorganic

* Recognisable with the help of a flora (see p. 421).

compounds carbon dioxide, water and mineral salts, in virtue of the energy of sunlight which their chlorophyll places at their disposal. *All* other living things must be supplied with ready-made food, and for this they are entirely dependent on the activities of green plants.

Many plants have come to depend, like animals, upon ready-made food obtained from other organisms. They are called **parasites** if they take their food from a *living* organism; the victim is called—rather ironically—the host. They are named **saprophytes** if their food consists of the *dead* remains of other organisms. Finally there are cases in which different plants live together, and each obtains food from the other. A partnership of this kind is called **symbiosis**—a living together for mutual benefit.

Any plant which does not possess chlorophyll must obviously be either a parasite or a saprophyte. Thus the Fungi—a group of lowly plants including mushrooms, toadstools, puff balls, moulds, etc.—being destitute of chlorophyll—can only grow in situations providing organic food, and they flourish as well in the dark as in the light. They are common in the humus of woods and fields. Their ancestors once possessed chlorophyll, but gradually lost it as they came to rely increasingly on ready-made food instead of building up their own.

Even among the flowering plants, certain species have quite ceased to develop chlorophyll, and now depend entirely upon food made by other plants; while others, though still capable of feeding themselves, take the opportunity, should it occur, of preying upon their neighbours. Some of the more interesting British examples of such abnormal methods of nutrition will be considered briefly in this chapter.

Total parasites.—Among British flowering plants the **dodder** is the best known total parasite. It is an annual, belonging to the convolvulus family, and its slender thread-like stems—yellow, pink or red—may be found twining (counter-clockwise) round the stems of flax, heather, gorse, clover, nettle (Fig. 146) and other victims, which they pierce by means of small suckers. A number of minute scale leaves occur on the stem of the dodder, but foliage leaves are quite absent; it has no roots, and

obtains all its food and water from the "host." The small, closely-set white or pink flowers produce very large numbers of small seeds, as with most other flowering parasites; and some seeds at least probably reach the ground sufficiently near other suitable plants to ensure their finding a victim on germination. The stem of the seedling early begins to sweep round, and if it

Photo. Henry Irving.

FIG. 146.—Dodder on Stinging Nettle.

is successful in grasping a suitable host the lower end of the parasite quickly dies, so that it loses all connection with the soil. If not, the whole seedling perishes.

Other total parasites are the **broomrapes**. They obtain their food from the *roots* of clover, broom, gorse and various other plants by means of adventitious roots which grow out from the tuberous base of the stem. The only part of the plant which ever appears above ground is the flowering shoot. Only small and brownish-yellow leaves, incapable of photosynthesis, are

produced. The seeds borne by the reddish-brown flowers are very numerous and extremely small. It is remarkable that they do not germinate except when quite close to a plant which will form a suitable host. The **toothwort**, another total parasite, grows in damp, shady places, commonly beneath hazel and other trees. It has a rhizome from which adventitious roots grow out and, on coming in contact with the roots of the host tree, form parasitic suckers. Its flowers are borne on pale yellow above-ground shoots in April and May.

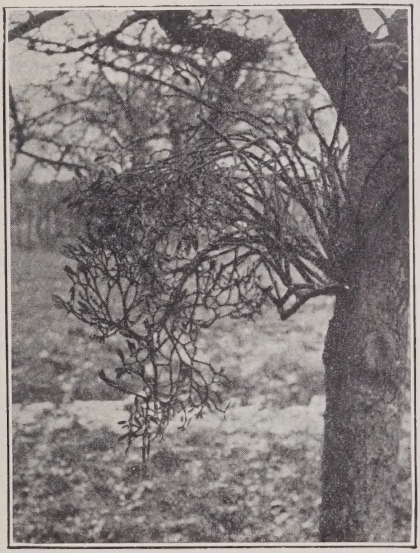
FIG. 147.—Small Broomrape, parasitic on Clover. *A*, single flower. (After Strasburger.)

It is to be noticed that all these parasitic plants show a great reduction of their vegetative organs, which are, indeed, to a large extent rendered unnecessary by the manner of life. On the other hand, the provision for reproduction shows no sign whatever of simplification, for the flowers are as well developed and exposed, and as successful in forming seeds, as in their more normal relatives.

Partial parasites.—In various families of British flowering plants, parasitism of a limited character is practised by certain species. Some of the most interesting examples occur in the foxglove family (Scrophulariaceae (p. 399)). They include the eyebright, the several species of *Bartsia*, lousewort, yellow rattle, and cow-wheat (common respectively on grassy heaths, roadsides, marshes, fields and woods), all of which, should opportunity occur, attack their neighbours underground by means of suckers on their rootlets. They are, however, by no means dependent on outside supplies of food, being well provided with green leaves, and therefore quite capable of supporting themselves entirely if necessary.

The **mistletoe** is often regarded as a partial parasite, but it is doubtful how far it obtains actual food, as well as water and

mineral salts, from the tree (poplar, apple, hawthorn, etc.) on which it grows. It has abundant machinery (leaves) for photosynthesis, and makes much if not all of its own organic food. The seeds are placed in position on the branches of the host by birds wiping their beaks after feeding on the sticky



Photo, Flatters & Garnet Ltd.

FIG. 148.—Mistletoe on Apple.

mistletoe fruits. The seeds germinate, and the peg-like roots pierce the tissues of the branch until they reach the wood and tap the water supply. Thereafter their growth keeps pace exactly with the development of the wood in the thickening branch.

Epiphytes.—Plants which normally live their whole lives perched on other plants are called epiphytes. They do not usually pierce the tissues of their host, as mistletoe does, but obtain from it merely the advantage of position—"a place in the sun." Unlike true climbers, they have no connection with the ground, but many tropical epiphytes, including flowering

plants and ferns, have remarkable leaves which form *cisterns*, in which rain water, with the detritus it has washed down the tree trunks, collects and is absorbed, either by roots which grow into the cisterns or by leaf hairs. Other tropical epiphytes are orchids and aroids with roots having a spongy layer, which absorbs and stores rain water. In some tropical epiphytes, the roots turn green and perform photosynthesis.

In Great Britain only a few plants are normally epiphytic; they are mostly lowly plants such as algae, lichens (Fig. 358), mosses and liverworts, but certain ferns also often show this habit. Many other sorts of plants—dandelions, grasses, etc.—however, live occasionally as epiphytes in such situations as the pollarded heads of willows, as well as on roofs, walls, etc., where blown litter, humus, etc., readily accumulates and forms soil.

27. BRITISH INSECTIVOROUS PLANTS.

PRACTICAL.

1. The sundew.—Obtain one or more plants of sundew. It may be found in bogs, in flower in July and August, or may be supplied by nurserymen. Study the leaves with a lens, and make drawings showing the arrangement and appearance of the hairs. Place very small shreds of lean meat or particles of hard-boiled egg on the leaves, and watch the behaviour of the hairs. Watch also what happens if a fly is caught in the sticky fluid secreted by the hairs.

2. The butterwort.—Also grows in bogs. In flower May-July. Experiment as with sundew.

3. Bladderwort.—Search for the plant in ditches and pools. The plant is submerged, and may be recognised by the small bladders (about $\frac{1}{8}$ inch diam. or less) on the finely-divided leaves. Open several bladders and look for remains of small insects, etc.

Flowering saprophytes.—The most striking British examples of flowering plants obtaining food *directly* from the dead remains of other organisms are found in our insectivorous plants—the sundew, the butterworts and the bladderworts. The first two live in bogs, where there is a shortage of nitrates (p. 279). These plants obtain their necessary supplies of combined nitrogen by catching

insects. The reddish radical leaves of the **sundew** are provided with numerous hairs or tentacles, each with a terminal knob secreting a glutinous fluid. A fly, attracted by the fluid, occasionally alights on the leaf and sticks fast. Then the neighbouring hairs bend over the victim and pour out a digestive fluid which

FIG. 149.—Sundew Plant (reduced) with flower and pistil.

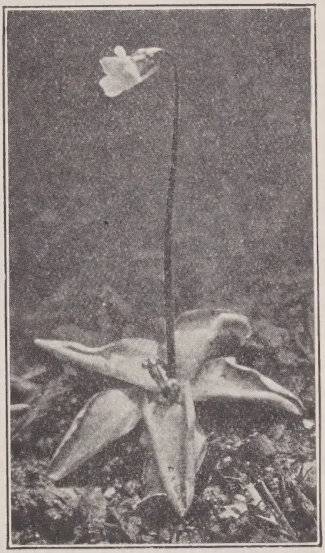


Photo. Henry Irving.

FIG. 150.—Butterwort.

kills it and dissolves its nutritive tissues. The "extract of fly" thus obtained is absorbed by the leaf and serves to nourish the plant.

The leaves of the **butterwort**, like those of the sundew, form a rosette round the base of the flowering stem. They are not provided with hairs, however, but a sticky fluid is poured out by glands on their surface, and retains flies which may settle on the leaves. The edges of the leaves are turned inwards to form a kind of groove in which the dead flies are digested and their useful juices absorbed.

The "bladders" of the **bladderwort** are small globular sacs on the deeply divided submerged leaves of the plant, which

grows in ditches and pools. Each bladder is provided with a little trap-door, guarded by stiff hairs and opening only inwards.

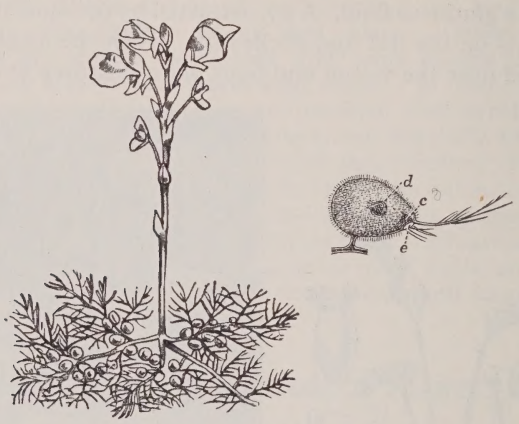


FIG. 151.—Common Bladderwort. On the left, whole plant, reduced. On the right, a bladder much magnified: *c*, "collar" indistinctly seen through the walls; *e*, entrance; *d*, a small crustacean which has been cap tured. (After Avebury.)

Through this, inquisitive water-fleas and other small pond animals find their way and are unable to escape.

28. FLOWERING PLANTS AND FUNGUS PARTNERS.

PRACTICAL.

1. The bird's nest orchid.—Look in thick, shady woods (especially beech) in June and July for the bird's-nest orchid, recognisable by the yellowish-brown erect stem (6-18 in. high) bearing a dense spike of pale brown flowers. Has it any green leaves? Do any green plants grow near? Is there an abundance of humus in the soil? Dig the plant up carefully and notice the nest-like tangle of short roots; then replant it.

2. Tubercular roots of Leguminosae.—Dig up various plants of the pea family (p. 384), and notice the small brown swellings on the roots. If possible, ascertain from farmers in your district how often they grow clover, beans or lucerne, and how the crop is treated. Compare the roots of any leguminous plants grown from seeds (*a*) in ordinary soil, (*b*) in similar soil

previously heated strongly in an oven, or on a shovel over a fire, to kill any forms of life present in it.

Flowering plants with fungus partners.—**The bird's-nest orchid** is often quoted as an example of a saprophytic flowering plant, but it should rather be considered a parasite, as will be seen presently. This plant is found in thick woods, especially beneath beech trees, where the light is too dim for photosynthesis, but where dead leaves and other plant-remains afford an abundance of humus. The erect shoot bears a close spike of pale brown flowers, but no green leaves, although a few brown scale-leaves are present. The plant would thus be still **incapable of photosynthesis** even in a good light. The flowering stem arises from a " root stock " bearing a tangle of stiff adventitious roots somewhat suggestive of a bird's nest in appearance. When these roots are examined microscopically they are always found to be infested by the very slender threads (called *hyphae*) of a fungus ; and it is now known that these fungal threads absorb the nutritious compounds from the surrounding humus and pass them on to the roots of the orchid. Evidently the fungus is saprophytic (obtaining its food from the dead humus), while the orchid is parasitic (obtaining its food from the living fungus). The relation between the two partners must, however, be one of mutual benefit or symbiosis (p. 226), since it is practically certain that the fungus obtains something useful from the roots of the orchid, in addition to the main food supply it derives from the humus.

A fungus partner on the roots of another plant is called a **mycorhiza.** It is common on most perennial flowering plants (notably orchids, heathers, etc., and forest trees), which differ essentially from the bird's-nest orchid in having an abundance of green leaves and making all their organic food ; in some such cases the fungal threads seem merely to supplement or replace root hairs, and only supply the higher plant with water and dissolved mineral salts which they take from the soil. The fungus benefits by supplies of organic food, but ultimately dies and is digested by its partner. In other cases the fungus partner is probably of even greater importance.

A partnership of a different kind is found in plants of the

family **Leguminosae** (peas, beans, clover, etc.), which normally possess on their roots small brown nodules or tubercles, like little warts. Microscopic examination shows these to be due to the swelling of the cortex, the cells of which are crowded with excessively minute rods. The rods are bacteria (very simple fungi) with a rare and remarkable power, that, namely, of taking in the *free nitrogen* present in the air of the soil, and combining it with other elements to make compounds which can be built up into living protoplasm. Carbohydrates made by photosynthesis in the green leaves of the leguminous plant, and passed on to its minute root-guests, furnish the latter with the energy to construct the valuable compounds of nitrogen; and when at last the bacteria in the nodules die, these compounds become available for the nutrition of the "senior partner." A few of the bacteria, which escape this fate, are left behind in the soil when in due course the roots themselves decay, and presently they enter the root hairs of other leguminous plants, increase enormously in numbers by rapidly repeated division, and find their way to the cortex.

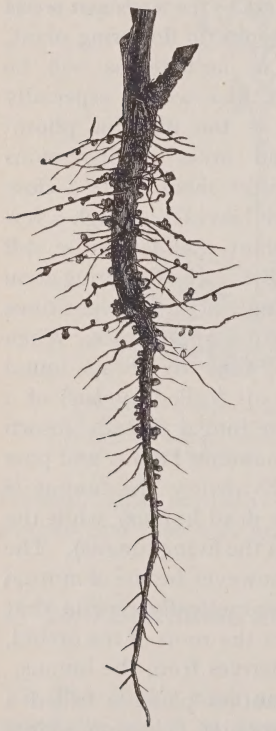


FIG. 152.—A root of Broad Bean, with numerous root-tubercles. (Reduced. After Noll.)

The Leguminosae have thus at their disposal an extra supply of available nitrogen compounds in addition to the nitrates and salts of ammonia which normally occur in the soil and are accessible to plants generally.* Farmers take advantage of this fact by growing a leguminous crop to enrich the soil with suitable nitrogen compounds, after its impoverishment by the growth of cereals (p. 121).

* See footnote, p. 119.

EXERCISES XIII.

1. What is a parasite ? Describe one plant, of which you have seen specimens, that adopts this mode of life. Show in what respects the nutrition of the plant you select differs from that of an ordinary green plant. (J.M.B. Matric.)

2. Give an account of the structure and mode of life of any *one* non-green plant. In what respects is its nutrition different from that of most green plants ? (J.M.B. Sch. Cert.)

3. From what sources and in what manner do green and colourless plants respectively obtain their supplies of carbon ? Describe experiments which support your statements. (C.H.L.)

4. Give an account of the natural history of British parasitic flowering plants. What structural modifications do these plants exhibit ? (C.H.L.)

5. Describe the method of nutrition of parasitic plants, distinguishing carefully between partial and total parasites. (L.M.)

6. What is meant by a semi-parasite ? Describe a British semi-parasite and give a clear account of its manner of life.

7. What are the chief uses of leaves to plants ? Name some exceptional uses. Dodder and mistletoe are both described as parasites, but the latter has green leaves and the former none. How do you explain this ? (N.F.U.)

8. Distinguish between parasites and saprophytes. Describe a native flowering plant of each kind. Where would you expect to find it ? (J.M.B. Hr. Sch. Cert.)

9. What is a parasite, and how does it differ from (1) a saprophyte, (2) an insectivorous plant ? Describe any parasitic plant known to you, and its mode of life. (J.M.B. Matric.)

10. Name any insectivorous plants you have seen, saying briefly by what means they secure their prey. Select one example, and describe carefully those features of structure and behaviour which appear to be connected with its habitat or mode of life. (J.M.B. Hr. Sch. Cert.)

11. How do green plants usually obtain their nitrogen ? Give an account of any other methods whereby nitrogen is obtained by plants. (C.P.)

12. Some pea seeds are sown in a pot of soil fresh from a garden. An equal number of similar seeds are sown in a pot of carefully sterilised soil. Both pots are watered when necessary with distilled water, and in all other respects the treatment given is that usually given to germinating seeds. What results would you expect in each case, and why ? (Cert.)

13. Name *three* gases that are always present in air. Tell briefly the parts they play in the life of a typical flowering plant. (J.M.B. Jun. Cert.)

14. What is the composition of the air ? Explain what part, if any, each of its constituents plays in the life of a green plant.

15. Describe any *two* cases of abnormal nutrition in plants you have studied. State precisely the corresponding modifications in the form and structure of the plants you describe. (J.M.B. Sch. Cert. and Matric.)

16. Give an account of the mode of life of *one* epiphyte. What are the features of the plant you select which fit it for its special mode of life ? Indicate clearly the sources of its food supply. (J.M.B. Matric.)

17. Give an account of the features characteristic of epiphytes. Under what conditions do they occur, and what is the biological advantage ? Mention any British plants you have seen growing as epiphytes. (J.M.B. Hr. Sch. Cert.)

18. Give some account of *either* climbing plants *or* epiphytes, mentioning the advantages and the difficulties of their mode of life and the ways in which the latter are overcome. (J.M.B. Matric.)

19. Briefly describe, with sketches, one example from each of *three* of the following biological types : climbers, parasites, epiphytes, insectivorous plants. (C.S.)

20. Mention a British insectivorous plant, state the kind of situation in which it is found, and describe its external features and mode of life. Say what you know of its behaviour in response to stimuli such as are connected with its insectivorous habit. (J.M.B. Hr. Sch. Cert.)

CHAPTER XIV.

THE IRRITABILITY OF PLANTS: TROPISMS.

29. GEOTROPISM.

PRACTICAL.

1. Roots and the influence of gravity.—(*a*) Germinate seeds of bean, pea, sunflower, etc., in moist coconut fibre in a box with one side (preferably sliding) of glass, so that the root system can be seen through the glass. Keep the glass covered except during observations.

In what direction do the radicles grow? When the radicles are about an inch long, mark some with Indian ink (using a stretched thread or a small brush) at intervals of $\frac{1}{10}$ inch, beginning at the tip, as in Expt. 1, p. 125, and replant the seedlings with the radicles horizontal. With a sharp knife cut off the tip (say $\frac{1}{20}$ inch) of the radicles of others transversely, and replant them horizontally. At frequent intervals examine the seedlings through the glass. Which radicles begin to bend downwards? *How soon* can you detect any curvature of the radicles? *How far* from the tip are (i) the curving region, and (ii) the region of most rapid growth during the time of curvature? What is the final direction of growth of the radicle? How do the decapitated radicles behave?

Leave several uninjured seedlings with their radicles horizontal for a little less than the time you have found to elapse before curvature begins; then remove their tips by a transverse cut. Do they curve after this treatment?

Which part of an uninjured radicle "receives" the guiding influence? Why do you think so? Can it be the weight of the radicle which causes it to bend downwards, as its weight causes a candle or a stick of sealing wax, supported horizontally at one end, to bend? Consider also the result of Expt. 2, p. 125.

(*b*) Leave the healthy seedlings until the tap roots form branches (secondary roots). What is the average angle between the vertical direction and the secondary roots. Cut off with scissors portions about an inch long from the tap root of a few of the seedlings, without disturbing their position. Set the box on end, and after a few days describe the change in direction of the tap roots and secondary roots. Do the bends obtained in Expt. (*a*) above remain, or do they straighten out? Describe carefully any special behaviour of the branches of the injured tap roots.

(*c*) Find out if the tertiary roots (branches of secondary roots) place themselves at any special angle with the vertical.

Compare tap roots, secondary roots and tertiary roots in this respect. How may a secondary root be made to behave like a tap root, and a tertiary root like a secondary root?

(*d*) *The Klinostat.*—What force always acts in a vertical direction?

Make a simple klinostat by attaching a rod (*e.g.* a steel knitting needle) to the minute hand of a cheap clock. To do this, soften a straight needle about 2 inches from the end by heating in a Bunsen flame, and bend it accurately at right angles; force the long limb to the middle through a large cork, then wire the short limb firmly to the minute hand so that the right angle is at the centre of the clock face. The end of the long limb may be smoothly supported in a short length of glass tube held in a clamp (Fig. 155). Germinate seeds in a pad of damp coconut fibre pinned to the cork. Start the clock, put the apparatus in the dark, and notice whether the radicles grow in any special direction. Try to explain the result.

2. Stems and the influence of gravity.—(*a*) Grow bean, sunflower and other seedlings in a pot or box, and when the young stems are two or three inches high mark the straightest and most vertical stem at equal short intervals with Indian ink. Then place the pot or box in the dark with the stems *horizontal*, and examine at intervals for a few days. Describe the result. Does the region of curvature of the stem coincide with the region of maximum growth? Is the erect growth affected by the force of gravitation? Observe the behaviour of stems of seedlings on the klinostat. Does it differ in any constant respect from that of the radicles? Is the hook on a bean plumule (Fig. 153) a response to gravity?

(*b*) Take up a sod of any tall grass, and put it in the dark with the stems horizontal. Keep the soil damp, and notice where any bending occurs to raise the stems to the vertical position. Treat

stitchwort, campion or other Caryophyllaceae (p. 378) in the same manner, and find what parts of the stem are specially sensitive to gravity.

(*c*) Dig up a horizontal rhizome (*e.g.* Solomon's seal) in early winter, and replant it in a vertical position, with the growing end uppermost. Examine it again a year later. How has its growth been influenced by gravity ?

(*d*) Estimate the angle which the flower tube of narcissus or daffodil makes with the vertical, then put a cut flower stalk in water in a test tube, fix it in position with cotton wool, and clamp the test tube so that the axis of the flower is vertical. Describe any bending and note where it occurs. Repeat the experiment with specimens kept in the dark.

3. Leaves and the influence of gravity.—Experiment with bracken, iris and other plants which have normally vertical leaf stalks or leaf blades, and find out whether their manner of growth is affected by the stimulus of gravity.

Irritability.—In former chapters we have met with many instances of plants behaving in some special way as a result of a change in their surroundings, and thereby escaping some danger or taking advantage of some favourable opportunity. Thus, changes in the abundance, or direction, of a plant's supply of moisture, light, or air are followed by greater or less development of its roots, stems or leaves, or by the placing of these parts in new positions. This power of self-adjustment to changes in the environment is called **irritability.** It is necessarily possessed in greater or less degree by all living things, whether plants or animals, for they could not survive without it. Any condition in the environment which causes an organism to behave in a special way is called a **stimulus**; and the special behaviour is called the **response** to the stimulus.

In this chapter we must consider some of the more obvious ways in which plants adjust themselves to such constant or changing conditions of the surroundings as affect their well-being.

Tropisms.—When a stimulus acts in a definite direction, and any part of the plant responds by placing itself in a line with the stimulus, or at some definite angle with the direction of the

stimulus, the response is called a tropism.* Thus, the force of gravitation at any point on the earth acts in a vertical direction, and is a stimulus which provides a "guide line" for the growth of roots, stems, leaves and flowers; somewhat as, by means of the plumb-line and level, it guides the work of a builder.

Geotropism.—Any directional growth of a plant-member which is prompted by the force of gravitation is called geotropism.† It is positive if such growth is vertically downwards, negative if vertically upwards; thus the radicle of a seedling is *positively* geotropic, while an erect stem is *negatively* geotropic. On the other hand, a part of a plant which persistently assumes an approximately horizontal position (*e.g.* rhizomes and the primary branches of tap roots)—that is, *across* the line of action of gravity—is said to be *diageotropic*.‡

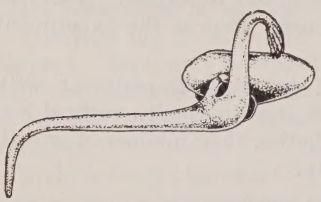


FIG. 153.—Seedling of Bean; after having been germinated, and the radicle had grown downwards and plumule upwards, its position was changed, so that they were horizontal. The figure shows its recovery, the root having curved downwards, and the plumule upwards. The former is positively, the latter negatively geotropic. (Dr. J. M. Thompson.)

It is not difficult to show by experiment that the examples of plant behaviour just mentioned—behaviour so obviously for the plant's benefit—really are instances of response to the stimulus of gravity. We have seen (Chap. II.) that the radicle of a germinating seed grows persistently downwards, and the plumule persistently upwards. The seedling may be moved (as by tilting the box in which it is growing), so that both plumule and radicle are horizontal, or at any other angle with the vertical, and yet both will be found to turn so that they once more grow straight up and straight down respectively (Fig. 153.) The bending is brought about by the more rapid growth of one side (the lower side of the plumule, the upper side of the radicle), as may be proved by marking the seedlings with Indian ink and observing to what extent the marks separate on each side. What prompts this unequal growth? Seeing that the same results are obtained, whether the

* Greek, *tropos*, a turning.
† Greek, *ge*, the earth.
‡ Greek, *dia*, across.

seedling is exposed to light or kept in the dark, and also when care is taken to ensure that the temperature and the supply of moisture and air are uniform in all directions, we may rule out variations of these conditions as possible causes of the seedling's behaviour. The only force remaining, which acts in a direction having any definite relation to the direction of growth, is the force of **gravitation**. It seems certain, therefore, that the downward growth of the radicle and the upward growth of the plumule are responses to the stimulus of gravitation.

The klinostat.—We cannot test the accuracy of this surmise by altering the line of action of gravitation—as we could alter the direction of some other stimulus—in order to examine the resulting behaviour of the plant; but instead we can do what amounts to the same thing—*i.e.* alter the position of the plant itself in a manner which will expose every side of it similarly in turn to the action of gravitation.

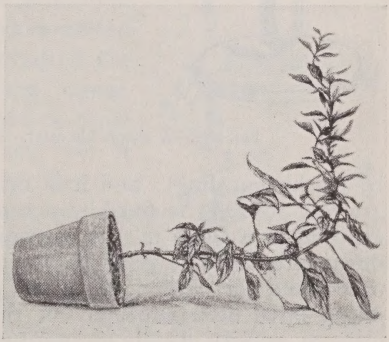


FIG. 154.—Illustrating the negative geotropism of the stem.

Thus, the stem of a plant growing in a pot laid on its side will turn upwards, even in the dark, to grow erect if undisturbed (Fig. 154). But if the pot (instead of being allowed to remain in one position) be rolled over slightly—to an equal extent—at regular small intervals of time, all sides of the horizontal stem in turn will be similarly exposed to the vertical force of gravity, and as a result the stem will show no tendency to bend upwards but will grow horizontally. The trouble of turning the plant round by hand may be avoided by using a clockwork arrangement, called a **klinostat**, the construction of a cheap and easily-made form of which is described on p. 238. By this means seedlings placed in various positions may be grown on a support slowly revolving in a vertical plane (Fig. 155). It follows that any particular side of the stem or root has no sooner been stimulated by gravity to more rapid growth (which if persisted in would cause curvature) than another side takes its place, to be affected in the same way. The result is that all sides are equally stimulated

in turn, and the plumule and radicle continue to grow in whatever directions they happen to point.

Again, the attraction of gravitation on any object may be overcome by centrifugal force (as when a stone is flung upwards

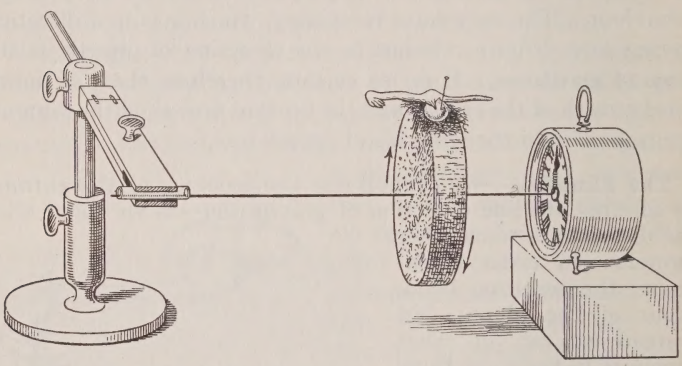


Fig. 155.—A simple klinostat. For description see p. 238.

by a whirling sling); and it is interesting to find that when a growing seedling is fixed to a rapidly revolving wheel (and so exposed to a force in the outward direction greater than the downward force of gravity), the radicle grows away from the centre and the plumule towards the centre. This result is what might have been expected on the assumption that it is the force of gravity which ordinarily guides the direction of their growth, and it therefore confirms that assumption.

Geotropism a vital response.—It might perhaps be thought at first that it is the *weight* of the radicle or tap root which causes it to bend downwards, just as the weight of an icicle or a stick of sealing wax, supported by one end in a horizontal position, soon turns it downwards. This cannot be the explanation, for it may be shown by Expt. 2, p. 125, that the radicle grows downwards with a force greater than the total weight of the seedling. Also, if geotropism were a mere mechanical result of weight, we should expect the more or less horizontal branches of the main root, as well as rhizomes, also to turn downwards, and they do not. Finally, the negative geotropism of horizontally placed stems—in a direction exactly opposite to the direction of their weight—would be inexplicable.

These considerations show that geotropism is no mere phenomenon of ordinary dynamics, but the effort of a sensitive living thing to adjust itself to its surroundings.

Receptor and effector regions of the root.—That geotropism is a vital response is illustrated strikingly by the loss of a radicle's sensitiveness to gravitation when its tip is removed. Such a "decapitated" radicle if placed horizontally continues to grow horizontally in spite of its weight, or if directed upwards grows upwards, until it has grown a new tip. The operation has evidently *either* prevented the radicle from receiving the signal to grow downwards which an uninjured radicle would have received when placed horizontally; *or* it has prevented the radicle from acting upon the signal. We can show that the former of these explanations is the correct one, for if the uninjured radicle of a seedling be kept horizontal for an hour or so and be then decapitated, it will presently turn downwards if left horizontal, or will turn to one side if planted vertically. Plainly, decapitation does not prevent the response to a gravitational stimulus received *before* decapitation, but prevents any subsequent reception of such a stimulus. For these reasons it is usual to speak of the tip as the **receptor** organ of the root, since it alone can receive the stimulus of gravity.

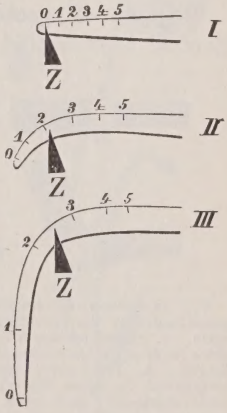


FIG. 156.—Geotropic curvature of the root of a seedling of Broad Bean. I, Placed horizontally; II, after seven hours; III, after twenty-three hours; *Z*, a fixed index. (After Sachs.)

The place called the **effector** region, where the radicle's response to the stimulus takes effect, is at some little distance from the point of reception of the stimulus, for the only part which shows any marked curvature is the region which is growing most rapidly (as shown by the greatest separation of equidistant lines of Indian ink; Fig. 156).

This fact is an example—there are many others as good or better (pp. 249 and 258)—of the transmission of "messages"

from one part of a plant to another. Such messages seem to be carried by certain special substances (called **hormones**) discharged into the sap at the point of stimulation and travelling with the sap to the responsive tissue. This is what makes it possible for a plant to correlate its activities so that each part works in harmony with others—even those at a distance—for the good of the whole. Any stimulus must act for a certain length of time (called the *presentation time*) in order to produce any response; after this minimum period of stimulation a certain time (the *reaction time*) elapses before the response becomes apparent.

Regions of geotropic curvature.—Geotropic curvature in general is restricted to the regions which are still growing in length, and is most marked in the region of most rapid elongation. While, however, the elongating region of a root is very short and not very far from the tip (in accordance with the resistance the tip has to overcome in forcing its way through the soil), a much larger part of the growing aerial stem is engaged in lengthening (without danger of buckling since it meets with so much less resistance). It therefore comes about that a geotropic curve in a root is usually sharper than one turning through the same angle in a stem. It will be remembered that most stems only elongate in the younger internodes, so that these are commonly the only parts which can become erect after being prostrated by wind (Fig. 154). In some families, however, certain older regions of the stem remain negatively geotropic throughout life. Thus, when a grass stem is laid horizontally (even in the dark), the soft swollen portions just above the older nodes resume active growth on the side next the ground (Fig. 157), and in this way bend the whole stem upwards until it is once more erect. In the family Caryophyllaceae (including campions, stitchworts, sweet William, pink, etc.) the nodes constitute similar "emergency growing points" by which the stem may be erected again at need.

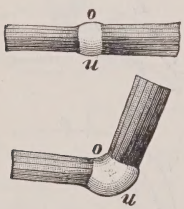


FIG. 157.—Geotropic erection of a grass-haulm by the curvature of a node. 1. Placed horizontally, both sides (*u*, *o*) of the node being of equal length. 2. The under side (*u*) lengthened, the upper side (*o*) somewhat shortened; as a result of the curvature the grass-haulm has been raised through an angle of 75°. (After Noll.)

Other instructive examples of stem geotropism are to be seen in many **flower stalks**, whereby the flowers themselves are held at a certain angle to the vertical, suitable for the visits of insects or the protection of the inside of the flower from rain, etc. Pansies, sweet peas, foxgloves, daffodils, etc., show this very well. If daffodil stems are held at an unusual slope, the angle which the stem makes with the axis of the flower alters so that the latter resumes its original inclination to the vertical. In this case curvature is confined to a small portion of the stem just below the flower.

Fig. 158.—Changing geotropism of the flower-stalk of Poppy. (After Strasburger.)

Changing geotropism.—If the tap root, which is positively geotropic, be seriously injured, one of its branches—which up to that time has been diageotropic—will become positively geotropic, and turn downwards to take on the duties and manner of growth of the tap root. At the same time, the branches of the new leader—hitherto not sensitive in any way to gravity, but growing indiscriminately in any direction—become diageotropic. In a similar way destruction of the terminal bud of an erect monopodial stem, such as that of a pine or larch, commonly causes a lateral bud—previously diageotropic—to become negatively geotropic and grow upwards as leader.

In some plants a change in the character of the geotropism is part of a regular succession of events. Thus the sympodial rhizomes of Solomon's seal, sand sedge, etc., are diageotropic in general, but become negatively geotropic in spring, as shown by the upward growth of their tips. The top of the flowering stalk of the poppy is in turn positively, dia- and negatively geotropic; for the flower bud hangs down, the opening flower is horizontal and the young fruit stands upright (Fig. 158). The flower bud of the daffodil is erect, but the opened flower is horizontal or droops slightly.

Geotropic leaves.—Leaves growing directly on rhizomes or other underground stems, respond to the stimulus of gravity by growing vertically upwards, at least until they have emerged from the soil. The leaves of some plants then spread out flat, but those of others remain negatively geotropic and continue to grow directly upwards. Iris leaves show this well (Fig. 159).

FIG. 159.—Rhizomes and negatively geotropic leaves of Iris. (After Figuier.)

30. HELIOTROPISM.

PRACTICAL.

1. Positive heliotropism of stems.—(*a*) Raise seedlings of various beans, pea, sunflower, etc., in pots. Select those with the straightest stems, and mark them at equal intervals with Indian ink. Then place the pots in a large light-tight box, in one end of which a hole has been cut. Notice the curvature of the stems. How soon do they begin to curve? On which side of the stem have the marks separated most? Compare the region of curvature with the region of maximum growth. Does the lighted or the shaded side of a stem grow more quickly? Refer to p. 240. Does curvature continue after the stem has placed itself in a line with the direction of light? Explain.

(*b*) Repeat the experiment with (i) blue, (ii) red glass in the hole at the end of the box.

(*c*) Place the clock of the klinostat (p. 238) on its back, so that the cork will revolve in a horizontal plane; start the clock, and raise seedlings on the pad of moist fibre on the cork, exposed to light from one side only. Do the stems grow erect? Explain.

2. Positive heliotropism versus negative geotropism.—Support a pot of seedlings in the dark box at such a level that the tips of the seedlings are higher than the hole in the end of the box. Which stimulus—heliotropism or geotropism—affects the stems more powerfully?

3. Positive heliotropism of flowers.—Make a list of all the kinds of flowers you can find (*a*) which regularly face south when growing in an open situation, (*b*) which turn through the day so as always to face the sun. Mark the upper end of the flower stalk with Indian ink, and try to find where the movement takes place in each case.

4. Diaheliotropism of foliage leaves.—(*a*) Find and record or photograph examples of plants, the branches of which bear leaves with their blades in one plane when lighted chiefly from one direction, but are radially symmetrical when lighted equally on all sides. How is the plane of the leaves related to the direction of the light ?

(*b*) Bind the stems of various potted plants to vertical sticks so that they cannot bend, and then expose the plants for several days to light from one side, and notice the effect on the leaves. Find out—by Indian ink marks—which part of the leaf stalk moves in response to the stimulus of one-sided light. Do both young and old leaves respond ?

5. Negative heliotropism.—(*a*) What parts of ivy, vine, Virginian creeper and ground-ivy can you find growing away from the light ? Try to find out (by covering with light-tight material the part of the plant concerned) whether the direction of growth is really determined by light. Look for other cases.

(*b*) Grow various seedlings close to the covered glass end of a germination box (p. 237), and, when the roots are well developed, uncover half the glass so as to expose some roots to light while others remain in darkness. Which, if any, roots turn away from the glass in consequence ?

6. Changeable heliotropism.—In June-September compare the behaviour of the flowers and the fruits of the ivy-leaved toadflax. Do they respectively face or shun the light ? In what situations are the seeds likely to be shed ? What advantage is gained by the change in the response of the flower stalk to the stimulus of light ?

7. The " perception " of light.—Sow seeds of millet or oat grass in pots, keep them in the dark until the seedlings are about an inch high above the soil, and then cover the tips (about $\frac{1}{6}$ of an inch) of half of them with opaque caps made by twisting tinfoil round a pin. Place the pot where it will be lighted from one side only, and show the results by drawings or photographs. Does the part which " perceives " the stimulus also respond to it ?

Heliotropism.—Guided by the "plumb-line" of gravitation, the negatively geotropic stems of seedlings and the aerial shoots of underground stems find their way to the surface of the soil, and thus come from the darkness into the light, upon the energy of which they will henceforth depend for life. It is only to be expected that, although **aerial stems** still continue to be influenced more or less, as we have seen, by gravitation, they rely mainly upon the light to guide their subsequent direction of growth. Indeed, they may ignore the gravitational stimulus altogether in cases where it conflicts with that of light.

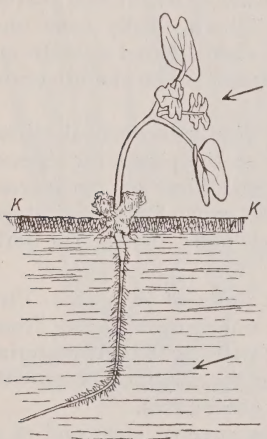


FIG. 160.—Seedling of White Mustard in a water culture, which has first been illuminated from all sides and then from one side only. The stem is turned towards the light, the root away from it, while the leaf-blades are expanded at right angles to the incident light. *K*, *K*, sheet of cork to which seedling is attached. (After Noll.)

We have already met with many instances (pp. 66, 199, etc.) of the more rapid growth of stems and leaf-stalks in a dim light than in a bright light, and have seen that it benefits plants by helping them to place their leaves in better-lighted situations. The fact that **bright light retards growth**, however, determines not merely the extent but also the *direction* of growth of a stem. For, if a stem be equally illuminated on all sides, it will be equally stimulated by light on all sides, and though its *rate* of growth may be affected by the intensity of the light, its *direction* of growth will remain unaffected. But if the light shining on one side of the growing region of a stem be much brighter that that on the opposite side, the two sides will grow at different rates—the dimly-lit side more quickly than the other. Plainly, the unequal growth will bend the stem so as to place it more nearly in the direction of the light, and will continue to bend it until the light shines equally on all sides. In this way the stem grows steadfastly towards a one-sided light shining in whatever direction, even (as Expt. 2, p. 246, shows) downwards, and in direct opposition to

the promptings of gravity, should the light come from below. The stem is therefore said to be positively heliotropic,* or (since artificial light as well as sunlight stimulates it) positively **phototropic.**†

Receptor and effector regions.—Heliotropic, like geotropic, responses are confined, as we should expect, to parts which are still growing in length. We saw that in the root, the part (the tip) which "perceives" the gravitational stimulus is at a slight distance from the part which responds to the stimulus. Similarly, the part of a stem which "perceives" the stimulus of light is not always the part which curves in response. Thus a young seedling of oat or other grass turns towards one-sided light by curvature in its *hypocotyl*; but may be "blinded," and prevented from curving to the light, by fitting a tiny light-tight cap on the tip of the *cotyledon*, the hypocotyl itself being left uncovered.

Heliotropic leaves and flowers.—By its positive heliotropism the stem thus does all in its power to carry the leaves into places favourable for photosynthesis; the **leaves** supplement these efforts by performing heliotropic movements of their own, which generally arrange the leaf blades roughly at right angles to the direction of the light; most leaves may therefore be described as *diaheliotropic.* It is, however, usually by *responsive* twisting and other movements of the sensitive leaf-stalk, or by alterations in the turgidity of the pulvinus (p. 58) that the blades are turned so as to face the light so effectively.

The **flower-stalks** of very many plants (*e.g.* foxglove, violet) are heliotropic in such a way that the flowers are made to face the light (Fig. 161); they thus attract the attention of insects and probably benefit also by the higher temperature. In some cases (passion-flower, sunflower, etc.) the curvature of the stalk responds so exactly to the changes in the direction of the light that the flowers turn daily to east, south and west in succession as the sun moves across the sky. Such a behaviour is, of course, not to be confused with circumnutation (p. 185), which is not due to any outside stimulus, but rather to a

* Greek, *helios*, the sun. † Greek, *photos*, light.

rhythmical impulse of increased growth passing round the stem. The flowers of the ivy-leaved toadflax—a wall plant—grow towards the light, their stalks being positively heliotropic; but

Photo. Henry Irving

FIG. 161.—Foxgloves growing at the edge of a wood. The flowers are all turned away from the wood, *i.e.* towards the light.

when the fruits are ripe and the seeds ready for scattering, the same stalks become negatively heliotropic, with the result that the fruits are carried to any dark chinks or holes in the wall, and the seeds are thus lodged in places suitable for germination.

Negative heliotropism, however, is comparatively rare. A few ordinary roots definitely avoid the light (Fig. 160), but the underground roots of most plants are unaffected by light. The adventitious aerial roots of the ivy, however, grow only on the

shaded side of the stem, that is, on the side nearest the wall or tree up which the plant is climbing (Fig. 127); and are thus produced only where they have a reasonable chance of becoming attached. The tendrils of the Virginian creeper and of the vine (p. 189) are also negatively heliotropic, and thus more readily find a support.

We saw in Chap. IV. that only certain of the light waves which together make up "white light" can supply the green plant with the special kind of energy it needs for photosynthesis, and that the red end of the spectrum is chiefly effective for this purpose. Curiously enough, it is the other end of the spectrum—the violet end—which alone can stimulate phototropic curvatures. In white light the plant finds both kinds of rays and is consequently guided in the direction affording the best conditions for food-making.

31. OTHER TROPISMS.

PRACTICAL.

1. Root growth towards water.—(*a*) Germinate seeds of pea, bean, mustard, etc., in damp moss or coconut-fibre near the covered glass end of an observation box (p. 237). When the roots are well developed, sketch their position as seen through the glass. After that, supply water on one side only, and notice the curvature of the roots towards the moist part of the moss.

(*b*) Germinate mustard seeds in damp moss or fibre in a small sieve hung up *horizontally*. Notice the growth, through the meshes and vertically downwards, of some of the roots. Then hang the sieve at an angle of 45°, keep the moss moist, and observe the curvature of the roots, first downwards again and afterwards away from the vertical and towards the moss.

2. Growth directed by contact.—(*a*) In an observation box arrange a layer of small pebbles with damp moss above and below, and plant various seeds so that the roots can be observed through the glass end of the box. Describe the behaviour of the tap roots when they touch the pebbles.

(*b*) Stroke a free tendril of (*e.g.*) white bryony and note *how soon* any curvature of the tendril can be detected. Stroke a similar

tendril for a slightly less time and then stop; does the tendril curve later? Stroke a twining stem (*e.g.* convolvulus, scarlet runner), and observe whether the stem curves at the point of stroking.

Hydrotropism.—Although the stimuli of gravity and one-sided light act as the chief guides of plant movements in definite directions, there are others which must not be lost sight of. Roots show a decided tendency to grow towards those parts of the soil which are moister than the rest; in other words **roots are positively hydrotropic.*** It is, of course, to the plant's advantage that the root should be guided by moisture rather than by gravity when these two stimuli conflict with each other; and Experiment 1, p. 251, shows that roots do in fact abandon their normal direction of growth if the necessary water happens to lie to one side. Cases of negative hydrotropism are unknown among flowering plants.

Contact tropisms.—Many examples of plants responding in some definite manner to the stimulus of contact are known (p. 258), but these are mostly non-tropistic. In some cases, however, contact or friction does give rise to unequal growth and therefore to bending in a definite direction. When one side of a tendril is rubbed, the opposite side grows more quickly, so that the tendril becomes concave at the point of stimulus. A continuation of the stimulus and its response naturally results in the tendril winding itself round the object causing the friction.

A specially interesting directional response to contact is shown when the *tip* of a root encounters unusual resistance, *e.g.* a pebble, in the soil. An impulse travels back from the irritable tip to the region where elongation is most rapid, and a one-sided growth here turns the tip away from the vertical. The root travels on more or less horizontally until the edge of the obstacle has been reached and, its positive geotropism being again unimpeded, resumes its downward path.

Growth guided by other conditions.—It is only to be expected that, up to a certain limiting point (p. 72), a greater abundance of any necessity of life (*e.g.* oxygen) in one direction will

* Greek, *hudor*, water.

make it easier for the part of a plant concerned to develop in that direction. On the other hand a specially unfavourable condition in one direction may limit development to the opposite direction, as when strong drying winds prevent the full development of leaves and branches on the exposed side of a tree, which in consequence leans to the leeward side. Many instances of directional growth caused in one or other of such ways might be given, but they cannot be classed properly as tropistic responses of the nature of those previously considered in this section.

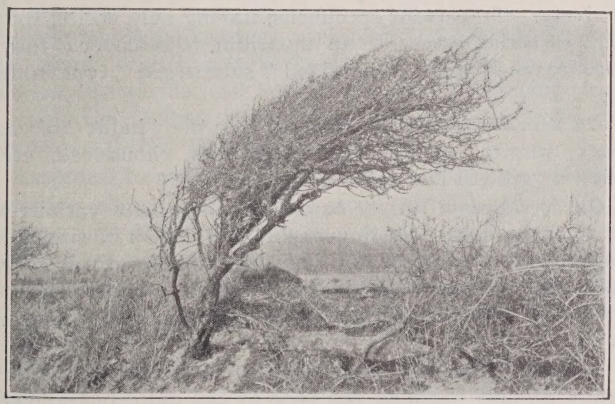


Photo. Henry Irving.

FIG. 162.—Wind-driven Hawthorn, winter.

Non-tropistic curvatures.—Certain curvatures—*e.g.* circumnutation of stems and roots, and the hooking of the underground plumule or hypocotyl of a seedling (p. 38)—are obviously useful under ordinary conditions, but do not depend on external stimuli. A bean plumule and a marrow or sunflower hypocotyl form the characteristic bend (Figs. 153 and 22) whether germinated in soil or moist air (and therefore without soil resistance to overcome), in the light or in the dark, or freed by the klinostat from geotropism. Such curvatures are habits too deeply ingrained in the race to be discarded whenever abnormal circumstances render them unnecessary. They are to be compared with the instincts rather than the reflex actions of animals.

32. NON-TROPISTIC RESPONSES.

PRACTICAL.

1. Influence of moisture. (*a*) *On leaf development.*—Raise seedlings of gorse in pots covered by a large bell jar, tilted so as to admit air, but with the air kept moist by a wet sponge or a pad of wet moss ; compare the seedlings, in respect of size and shape of leaves, with others of the same age grown outside the moist chamber.

Compare the leaves of plants of water buttercup (Fig. 188) growing in swift streams, ponds or ditches, and shallow pools respectively. Transplant specimens, having only entire, rounded (floating or aerial) leaves, to an aquarium, to discover if they will produce leaves of the finely-divided " submerged " type in deeper water.

(*b*) *On stem development.*—Find out how the " habit " of various compact rosette plants (*e.g.* saxifrages, houseleek, etc.) is modified by growth in a moist atmosphere.

(*c*) *On development of root hairs.*—(i) Germinate various small seeds, some on damp blotting paper, and others of similar kind on muslin just over water, so that their radicles dip into water. Examine the radicles of both lots in position with a lens, and describe any difference in the extent to which they form root-hairs.

(ii) Grow hyacinths or other bulbs in " hyacinth glasses " with the water at first touching the base of the bulb, but allowed to evaporate later, so that the youngest roots do not reach the water for some time. How do the roots in the air differ from those in the water ?

2. Influence of light. (*a*) *On size of leaves.*—Compare the average size and thickness of beech leaves grown in a good light with those of beech leaves grown in the shade of a wood. Cut sections if possible, and compare the thickness of the palisade parenchyma (p. 105) of such sun and shade leaves.

(*b*) *On length of stem.*—Revise Expt. 1, p. 181.

(*c*) *Sleep movements.*—Look for plants (*e.g.* clover, wood sorrel, daisy, etc.) the leaves or flowers of which close or otherwise change their positions at night, and find (by inverting a flower pot or box over them) whether lack of light will make them " go to sleep " during the day. Draw the leaves of wood sorrel and clover in the day and night positions. In each case notice whether the

upper or the lower surfaces of the leaflets are sheltered from the air in the night position.

(*d*) *Development of flowers.*—Compare the abundance of flowers on plants of the same kind growing in shaded and well-lighted places respectively.

3. Influence of temperature.—Take daily readings of the temperature of the soil at the same place and hour, with the bulb of the thermometer six inches below the surface. Record also the dates of appearance of various seedlings and annual shoots and flowers of herbaceous perennials, and of the opening of tree buds ; and try if these events can be hastened by keeping the specimens in a warm room. Compare, for example, the dates of flowering of tulips, etc., kept indoors, with those of plants from the same lot of bulbs grown in the garden. Compare the dates of flowering of similar plants (*e.g.* hyacinth) in a wood and in an open field. Which has the warmer soil ? Test the effect of varying temperature upon the "sleep movements" of various potted plants which have different day and night positions.

4. Response to contact.—(*a*) Flick with thin string the leaflets of sensitive plants (mimosa and wood sorrel), and notice their behaviour. (*b*) With a bristle touch the inside of one of the separated flaps of the stigma of a musk flower, and notice that the flaps come together. (*c*) With a bristle touch the top of the stamens of a corn-flower or knapweed ("hardhead"), and notice how they contract and sweep out pollen. (*d*) What responses to contact are shown by adventitious roots of ivy, the tips of the tendrils of Virginian creeper and vine, and the tentacles on a leaf of sundew ?

5. Response to injury.—Whenever possible study the stages of growth of new tissue over the surface exposed by sawing off a branch of a tree. Collect specimens of oak "apples" and cut open these galls to find the contained insect, or notice the hole by which it has escaped. Collect gall-bearing leaves of oak and other trees. Cut up dandelion roots and the thick scales of lily and tulip bulbs, and plant the pieces in moist fine soil. Put cut twigs of willow, rose, etc., in water or moist earth, and notice the formation of adventitious roots.

Non-directional responses.—Among the ways in which plants adjust themselves to changes in their environment we have to include not only tropisms—that is, the turning of plant members to take up positions depending on the *direction* of

a one-sided stimulus—but also responses prompted by the *amount* rather than the direction, of light, moisture, warmth and other conditions affecting their welfare. These non-directional or non-"tropistic" responses may either take the form of definite movement, or show themselves by differences in the rate of growth or the extent of development of such members as stems, roots, leaves or flowers.

"Sleep" movements.—Very striking are the movements by which certain plant-parts alter their position from time to time during the day. **Flowers** in many cases close when the insects on which they depend for pollination are unlikely to be abroad, and thus escape an unnecessary exposure of the readily injured pollen and nectar. Thus the flower-heads of the daisy and many other Compositae (p. 402) close by the bending inwards of their outer florets as night comes on (Fig. 163), though some members of the family (*e.g.* goat's-beard or "John go to bed at noon") close in the middle of the day. Similarly, the individual flowers of tulip, crocus, wood anemone, speedwell and many other plants shut at dusk. On the other hand, "evening primrose," tobacco, and other flowers pollinated by night-flying moths, remain closed in the daylight but open at twilight. In some, if not all, cases the opening and closing movements of flowers are due to unequal growth of the inner and outer faces of the sepals or petals, until these have reached their full size.

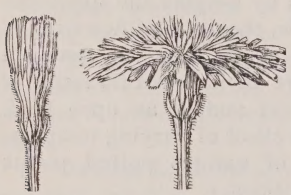


FIG. 163.—Flower head of Rough Hawksbit, closed when kept in darkness, open when illuminated. (After Detmer.)

The **leaves** of many plants protect themselves from excessive transpiration at night, as well as during very hot weather, by making certain movements which shield their transpiring surfaces from full exposure to the air. Among common plants the white clover and wood-sorrel show this very clearly.

The ternate leaf of the *clover* has more stomata on the upper surface than on the lower, and in the sleep-position it is the upper surface which is chiefly covered. This result is attained in three stages. First, the leaf stalk becomes upright; then

the pair of leaflets next the stalk move so that they hang vertically, with their "upper" faces together; lastly the terminal leaflet is bent over the other two with its "upper" face downwards, becoming folded along its mid-rib at the same time to cover them in, like a folded sheet of paper enclosing two unfolded sheets (Fig. 164). The leaves of various other plants of the clover family (Leguminosae), *e.g.* bird's foot trefoil, scarlet runner bean, acacia, mimosa, also show sleep movements.

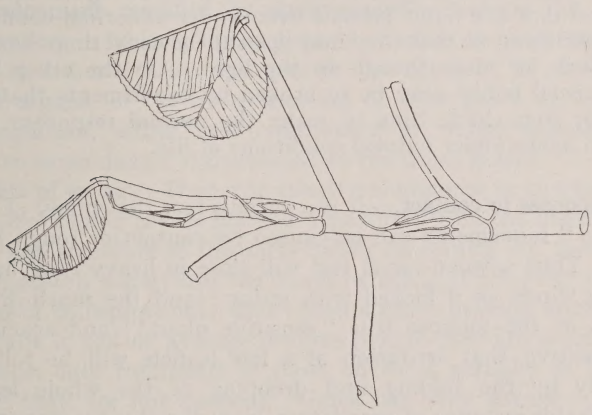


FIG. 164.—Prostrate stem of White Clover, with leaf-bases, stipules and leaf-buds. A leaf in the sleep-position is introduced behind. Natural size. (From Miall's *House, Garden and Field*, by courtesy of Mr. Edward Arnold.)

In the *wood-sorrel* (allied to the geraniums), which has a ternate leaf somewhat resembling that of clover in appearance (compare Figs. 182 and 192), the great majority of the stomata are on the *lower* surface; and the folding of the leaf takes place in such a manner that the lower surface is covered. All three leaflets droop with their mid-ribs against the erect leaf-stalk, and are folded so that each half lies with its lower face against that of the neighbouring half-leaflet. The position is shown in Fig. 130; it is somewhat suggestive of a folded umbrella.

Cause of "sleep" movements.—Sleep movements of leaves are brought about by **alterations of turgidity** in the swollen pulvinus (p. 58), which can be seen at the base of the stalk of the leaf

or leaflet concerned. In many cases this alteration of turgidity —like the **variation in the rate of growth** of the petals or sepals, which results in the opening or closing of flowers—is a response to the combined stimulus of varying temperature and light, as day and night succeed each other; but in some cases it can be excited by a change in one only of these conditions. Wood sorrel leaves will often close at the mere passage of a thick cloud across the sky; while a closed tulip will open in the dark if taken into a warm room. Moreover, plants may become so accustomed to opening and closing their leaves or flowers at regular intervals of time that the habit persists even under abnormal conditions of experiment, so that they may open at the usual time though in the dark, or close though in the light. On the other hand, their usual habits may be so broken by experiments that they fail for some little time to make the normal responses when placed again under natural conditions of life.

Responses to contact.—It is a curious fact that many of these "sleep" movements can be caused by contact or rough handling. Thus a wood-sorrel leaf will close in heavy rain, hail or strong winds, or if flicked with string; and the much-divided leaves of the mimosa (the "sensitive plant") and acacia are so sensitive that irritation of a few leaflets will be followed quickly by the folding and drooping of the whole leaf—a remarkable instance of correlation, since the obvious movements are due to responses some inches from the point touched.

Other oft-quoted instances of contact responses are provided by the stigma of the musk flower and the stamens of the barberry and knapweed flowers. The musk stigma has two flaps which remain apart until something (normally a pollen-laden insect) touches the inside of one, when they close together (p. 400). Contact of an insect's legs or proboscis (or a bristle in the hand of an experimenting botany student) with the stalks of barberry stamens will cause the latter to spring up so suddenly as to scatter a little shower of pollen dust on the intruder, which, if an insect, would be likely to carry it to another flower. The behaviour of the stamens of knapweed when touched (p. 406) is also noteworthy.

We have already noticed that the adventitious roots of the ivy—guided by negative heliotropism to a wall or tree trunk—

are stimulated by contact to secrete a sticky fluid which attaches them to the support (Fig. 127), and that the tips of the tendrils of vine and Virginian creeper are similarly stimulated to spread out and form adhesive cushions. The behaviour of the hairs or tentacles on a sundew leaf (p. 231), when a fly is caught in the sticky fluid they produce may not be purely a response to contact; the chemical nature of the fly's juices doubtless is also responsible.

Development modified by environment.—Perhaps the commonest way in which plants adjust themselves to their environment is either (1) by the greater development of specially useful organs, or (2) by a stunting of such parts as, in the circumstances, either are unnecessary or would expose the plant to some danger if developed to the usual extent.

Effect of water.—Thus, the relative abundance or shortage of the water supply causes marked departures from the usual size, shape and structure of the parts chiefly concerned, viz. the roots (which absorb water) and the leaves (which give off water in the process of transpiration). Many plants which produce abundant root hairs in soil of average dryness (where they are necessary) will form only rudiments of hairs on roots actually in water (where they are not needed). Gorse has very narrow leaves, which transpire very slowly, when the plant grows—as it mostly does—on heaths, where the soil is very dry (p. 275); but gorse seedlings artificially raised in moist soil and air have much larger and wider leaves. Houseleek, another plant of dry situations, escapes dangerously rapid transpiration because its stem internodes remain undeveloped, and therefore its leaves are crowded together in a close rosette; but if the same plant be moved to a damp atmosphere and abundantly watered, its leaves will become separated by distinct internodes, the stem growing to an unusual length.

A reaction of a rather different kind (since it does not depend on the amount of water the plant can absorb or retain) is shown by water buttercups. When these plants live in deep, and especially in flowing, water they develop not only the usual aerial leaves but also special submerged leaves (Fig. 188). These are divided into thread-like segments, and therefore

expose a far greater surface for the absorption of dissolved carbon dioxide from the water, and are unlikely to be torn by the force of the current. The seeds of such plants, however, if germinated in the mud of a shallow pool, give rise to water buttercups having only the undivided (aerial) type of leaf; and, conversely, plants raised in deep water, from seeds of the shallow-water form, produce both kinds of leaves.

Effect of light.—The phenomena of etiolation (pp. 66 and 199) as well as of heliotropism (p. 246) furnish excellent examples of the effect which varying **intersity of light** has upon the *rate* of development of individual stems and leaf-stalks, etc. But light affects not merely the rate of development but also the *extent* of development. Many plants form larger but thinner leaves, when growing in the shade of a wood, than plants of the same species growing a few yards away in similar soil, but in full light. Such "shade leaves" are found on microscopic examination to have fewer layers of palisade parenchyma in their mesophyll (p. 105) than "sun leaves" of the same species have. The greater efficiency gained in a dim light by having the assimilating tissue spread over a greater surface is obvious. It is common knowledge that plants in general flower most freely in the most sunny situations—a useful response, since flowers in a good light are most easily seen by insects.

Effect of temperature.—The effects of changes of **temperature** upon plant growth can not only be described but also to some extent explained. It is well known that seeds, which have lain in the ground through the winter, germinate in a definite order which depends largely upon the temperature; so that some seedlings are to be found growing vigorously in February while others do not appear until several months later. Each embryo plant has to wait until the soil warms up to the temperature at which the enzymes in the seed can render the various stored foods soluble, and the protoplasm can become active; and the temperature necessary for this change varies in different kinds of plants (compare broad beans and French beans, p. 26). The same is true of the growth of the annual shoots from the buds of trees or from herbaceous perennials which have wintered underground. In a mild spring or a warmer climate the new

shoots and flowers of the same plants appear earlier than usual; and artificial heat is often used to hasten by months the flowering of such herbaceous perennials as tulip, hyacinth, crocus, snowdrop, daffodil, etc.

Effect of injury.—Finally, the effects which injury has on the growth of plant tissues must be mentioned. It causes the cells in the immediate neighbourhood to divide rapidly and increase greatly in numbers, forming new tissue which heals the wound. This new tissue, or **callus,** may be observed gradually spreading, from the cambium of the edge, over the cut surface

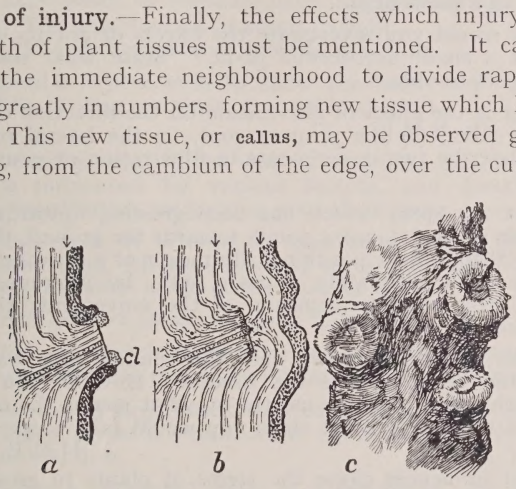


FIG. 165.—Healing of wounds caused by cutting off lateral branches. First, formation of callus (*cl*), after which three seasons of growth were required. (After Curtis.)

left on a tree when a branch has been cut or sawn off (Fig. 165), as well as on injured dandelion roots, etc. In the operation of "grafting" or "budding," by which a gardener joins a shoot or bud of one plant to the branch of another, care is taken to bring like tissues together—especially cambium to cambium—and the new cells formed effect a vital continuity between stock and scion (p. 212) so that they grow as one.

The rapid production of new tissue as a result of injury is well seen in the "galls" which form round the eggs laid by various insects in the leaves, etc. of oak and other trees. Still more remarkable as a response to injury is the growth of complicated adventitious buds—capable of developing into leafy and flowering shoots—on damaged roots of dandelion and other plants, and on cut or broken edges of the scales of bulbs (p. 220).

EXERCISES XIV.

1. What do you understand by geotropism? Describe one or more simple experiments by which you could demonstrate its existence in a plant-organ. (C.J.)

2. How would you investigate the effects of gravity upon the organs of a small herbaceous plant? State what results you would expect to obtain. (C.J.)

3. What is the effect of gravitation on the direction of growth of (*a*) the stem, (*b*) the primary root, (*c*) the lateral roots of a plant. Describe two experiments in illustration of your answer. (O.S.)

4. If an ivy spray which has been growing upwards is bent downwards so that its apex points towards the ground, the leaves gradually change their position. By means of a drawing describe the spray as it ultimately appears, and, by reference to leaf structure, give some explanation of the movements that have taken place. (Cert.)

5. When plants are grown near the window of a room their shoots often bend towards the window. How do you account for this behaviour? State clearly by what means the curvature is brought about and what steps you would take to prevent the effect. (J.M.B. Matric.)

6. What influences cause the stems of plants to grow in one direction rather than in another? Describe any examples which you have seen, showing the effects of these influences on plants growing in their natural surroundings. (C.S.)

7. How could you show by experiments the effect of light on the direction of growth of stems and leaves?

What peculiarities of form are exhibited by plants grown in the dark? (O.S.)

8. What influence has light on the configuration, structure, and orientation of leaves? (L.L.A.)

9. Describe two kinds of climbing plants, stating in each case exactly how and why the plant climbs. (J.M.B. Hr. Sch. Cert.)

10. How would you investigate the manner in which the root of a bean seedling grows in length? What results do you obtain?

Can you, without putting any obstacle in its path, cause the root to grow otherwise than vertically downwards? (Prel. Cert.)

11. It is known that roots under normal conditions usually grow downwards. Why is this? Mention any experiments that may be adduced in support of your statement.

What would be the effect of slight watering on plants growing in the garden during a dry season, and why, when such a watering has once been given, must it be repeated? (Cert.)

12. What external conditions influence the direction of growth of stems? Describe an experiment proving, in the case of one of these conditions, that it is the cause of the effect produced.

13. What kinds of sensitiveness are shown by plants? Describe an experiment to illustrate each of the following:

(*a*) The sensitiveness of stems to light.
(*b*) The sensitiveness of roots to moisture. (L.M.)

14. Describe experiments to show the behaviour of roots to light and to varying amounts of water in the soil.
(J.M.B. Hr. Sch. Cert.)

15. Give an account of the way in which the direction of root growth is influenced by various factors, and describe, with sketches, experiments supporting your statements. (Cert.)

16. What facts of interest do you know about (i) the root of the broad bean, (ii) the leaves of clover, (iii) the fruit of the potato, (iv) the stem of the scarlet runner bean? (Cert.)

17. Write a short essay on plant movements.

18. What are the characteristics of an etiolated plant? Mention plants which are purposely etiolated during cultivation.

19. Describe an experiment that demonstrates the importance of *light, either* (1) as a stimulus, or (2) as a necessary agent in starch manufacture. (J.M.B. Jun. Cert.)

20. Outline a connected series of experiments, not more than six in number, which you could carry out in any ordinary classroom to illustrate for your pupils the relation of plants to their water supply. (N.F.U.)

CHAPTER XV.

ECOLOGY: THE STUDY OF PLANTS IN THEIR HOMES.

Practical.

1. Vegetation maps and charts.—(*a*) Make vegetation maps of your district (by duplicating tracings from the six-inch ordnance survey map), and show by different tints woodland, bushland (scrub), permanent grassland, heath, moor, marsh, and cultivated land. Use a geological survey map to find out what rocks are next below the soil of each. Make notes of the slope and aspect, and of the nature of the soil (p. 107); if carbonates are absent, find out if the soil is acid, by shaking with solution of potassium salicylate (p. 491). Every month make a list of the most conspicuous plants of each kind of land, noting whether they are in leaf, flower or fruit.

(*b*) *Quadrat charts.**—For more detailed study, mark out a typical square area with tapes, and from time to time show on squared paper, by shading or initials, the positions of conspicuous groups or of individual plants. For the former, a square of 25 ft. side, with tapes at intervals of 5 ft. and charted to a scale of 1 : 60, is convenient; for the latter, a square of 1 metre side, charted to a scale of 1 : 10, is best. In this way, keep accurate records of the plants, their effect on each other and their seasonal changes.

(*c*) *Transects.**—On a line drawn to scale, mark by symbols or initials the positions of the plants touched by a tape laid at right angles across a hedge, or the edge of a wood or pond, or along other directions of change of habitat.

2. Colonisation.—Clear of plants a measured small area of ground in various situations, *e.g.* a garden, a field, a wood. Record the order in which various plants appear. How did each arrive? Is it an annual, a biennial, or a perennial?

* See Tansley's *Practical Plant Ecology* (Allen & Unwin).

If possible observe the difference in the character of the ground flora which follows the periodical cutting of coppice in a wood. Account for it.

3. Influence of animals.—Isolate (*e.g.* by wire netting attached to posts at the corners) a small area of usually grazed ground. Observe and record any differences seen to result from the protection thus afforded. Make notes of any effects which you have observed sheep, rabbits, moles, ants, slugs and earthworms respectively to have upon the local vegetation.

4. Succession.—Record any cases you find (by observation from year to year) (*a*) of any particular species of plant killing and replacing others, (*b*) of one plant association encroaching on another at such places as sand dunes, the edge of a wood, the edge of a pond. Which invaders have rhizomes?

5. Stratification. (*a*) *Below ground.*—In a dry oak wood dig up the underground parts of soft grass, bluebell and bracken, and note at what depth each occurs. How does this make it possible for the plants to come up, in turn, at the same place?

(*b*) *Above ground.*—Look for examples of plants deriving benefit from others which bear foliage at a different level (i) in a wood, (ii) in a hedge, (iii) in a marsh or fen.

6. Ecology and agriculture.—The Director of the Rothamsted Experimental Station makes the following suggestions for ecological study needed in agriculture:

SCHEME FOR FIELD NOTES ON ARABLE WEEDS.

INFORMATION REQUIRED.

1. Place and county.
2. Date.
3. Soil (clay, loam, sand, peat, etc.).
4. Geological formation.
5. Manuring.
6. Crop.
7. List of weeds:
   - (*a*) Dominant.
   - (*b*) Sub-dominant.
   - (*c*) Distributed.
   - (*d*) Occasional.
   - (*e*) Scarce or rare.
8. Calcium carbonate content of soil.
9. Any further information available.

CLASSIFICATION OF WEEDS (see 7 above).

(*a*) *Dominant.*	I. Far more abundant than other species.
(*b*) *Sub-dominant.*	II. Less plentiful than the dominant species, but much more prevalent than other species.
(*c*) *Distributed.*	III. Includes the majority of weeds.
(*d*) *Occasional.*	IV. A few scattered specimens occurring in the field.
(*e*) *Scarce or rare.*	V. Only one or two isolated specimens occurring over a large area.

Notes would also be of interest dealing with

1. Flora of special areas as
   - (*a*) Round gateways.
   - (*b*) Paths.
   - (*c*) On sites of old stacks.
   - (*d*) Sites of old manure heaps.
2. Injurious or poisonous plants.
3. Parasitic plants, as Dodder, Broomrape, Bartsia, Yellow-rattle.
4. Any general information.

33. PLANTS LIVING UNDER CONDITIONS OF DROUGHT.

The main problems of ecology.—In Chapter XIV. we were concerned with certain ways in which *individual* plants are able to adapt themselves to changing environment. It is obvious, however, that there is a limit to a plant's "plasticity," or power of changing its manner of growth to suit its surroundings; and that in a somewhat different climate or soil the plant might be unable to exist at all. We have now to consider how various climatic and soil conditions, and the influence of mankind, animals and other vegetation account for the facts that in a wood, for example, certain species, but not others, are found growing together to form a **plant community**, having distinctive characters of its own; while on a moor entirely different forms occur as neighbours, and a marsh supports a third and equally characteristic group of vegetation. The study of the correspondence

between plants and the conditions of life in their natural homes is called plant **ecology**.*

The most generally useful clues to an ecological problem are found by considering the special limitations imposed on the plants by their habitat. A student who realises how important to plants are an adequate supply of water and air to the roots, and of light to the leaves, is in a position to understand at least the main difficulties with which plants are beset in specially dry soils, in soils constantly soaked with water, and in dimly lighted situations respectively. It seems clear that plants living successfully under such limitations must be "making the best of a bad job" rather than leading an ideal existence; they must be there not so much because circumstances are specially favourable to them, as because by some means they are able to survive hardships which to most plants would be fatal. It becomes a question of the highest interest how the plants manage, each in its own way, to evade or overcome the difficulties of the situation in which they sprang up and in which—since they have but a limited power of locomotion—they are compelled to pass their lives.

The sand-dune plant formation.—In earlier chapters we have learnt something of the various uses of water to plants, and we can understand that the danger of becoming too dry is, on the whole, the greatest which plants have to face.

Sandy soils allow water to pass through them very freely, so that any rain falling on them drains quickly away from the surface layers. This condition is most marked in the **sand dunes** above the sea beach. The actual scarcity of water in the soil is, however, only one of the difficulties experienced by plants of the sand dunes; for the bright light and almost incessant breeze of the seaside, together with the heating of the lower air by reflection of the sunshine from the white sand (where this is exposed), form conditions which favour transpiration to the utmost. These facts are true of all parts of the dune, from its seaward side to the heath or links into which it may merge on the landward side; and the plants growing on it—all

* Greek, *oikos*, a home.

living under the special conditions mentioned above—are often grouped together by botanists to form what is called the **sand-dune formation.** This may be divided roughly into three plant "**associations,**" according to the stage of development of the formation, for the sand of the dune varies much in its degree of consolidation.

(*a*) *First stage.*—The seaward edge of the dune usually consists of drifting, loose sand, and the most abundant plants

Photo. W. B. Crump.

FIG. 166.—Sandy Foreshore, Somerset. *D*, line of débris at high-tide mark; *S*, line of Saltwort; *C*, incipient dune with Sea Couch-grass; *M*, crest of dune covered with Marram Grass.

here are the sea couch-grass (Fig. 166, *C*) and the sand sedge (Fig. 131). The plants of this part of the dune are therefore called collectively the *sea couch-grass association*, because the sea couch-grass is "dominant" (p. 267) among them.

(*b*) *Second stage.*—The crest of the dune is occupied by sand which, though held together to some extent by the rhizomes and roots of the plants growing in it, is constantly changing in form by removal and by new supplies blown from the shore.

The dominant plant on these "shifting dunes" (Fig. 166, *M*) is the marram grass (also called star grass), and therefore the plants here form the *marram-grass association.*

(*c*) *Third stage.*—Further back from the sea, on the leeward and sheltered side of the crest, is the oldest part of the dune, which has passed previously through the stages now represented by blown sand and shifting dunes. In this region—called the fixed dune—the sand is most consolidated, as a result of being bound together by the underground parts of marram grass and other plants of similar habit, and there have been time and opportunity for other kinds of vegetation—at first shallow-rooted annuals and, later, such perennials as rest-harrow, bird's-foot trefoil, stonecrop, thyme, etc.—to grow here, which would have failed to establish themselves nearer the sea. Often the creeping willow (Fig. 167) is the most characteristic plant of this part, and in such cases it and the associated vegetation form what is called the *creeping-willow association.*

Photo. Henry Irving.

FIG. 167.—Creeping Willow.

Adaptation to environment.—No better example of adaptation to environment could be found than the structure of the **marram grass.** It has wiry underground stems (rhizomes) growing horizontally and branching freely. Hard and pointed buds at the tips of the various branches make it easy for the rhizomes to spread in all directions through the soil. At the widely separated nodes, long, fibrous adventitious roots and sheathing leaves grow out, and in the axils of some of these leaves pointed shoots arise which grow upwards and at the surface produce the well-known tufts of long and narrow foliage leaves (Fig. 168). These have sharply-pointed tips which are obviously a help in

piercing the sand. The power of growing rapidly up to the surface again and producing a new set of adventitious roots at a higher level, after being buried in sand, is a great factor in the marram's success; moreover, the matted underground stems and long roots are evidently suited admirably for holding the plant firmly in position and for finding water. Two problems, which in such a situation are of more than usual difficulty, are thus solved.

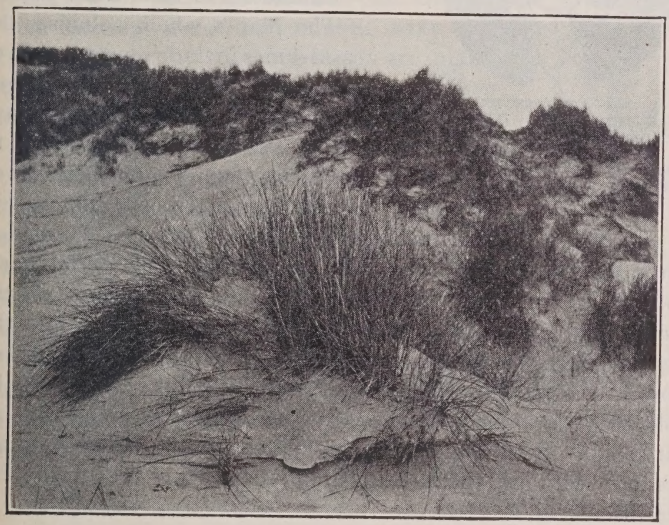


Photo. W. B. Crump.

FIG. 168.—Marram Grass growing on the crest of a sand dune.

An even more pressing need, as we have seen, is the restriction of transpiration from the leaves above the surface. How effectually this is accomplished may be understood from Fig. 169, which shows a transverse section of the leaf. The leaf is folded lengthwise, and its inner ("upper") surface is so ridged that the stomata open into sheltered grooves, in which the air is more or less stagnant, so that they are protected from the drying breeze. Moreover, the hard and soft portions of the leaf are arranged in such a way that the leaf folds itself up more tightly when the water supply becomes less, but unfolds itself in proportion as it receives more moisture and freer transpiration becomes safe. Another interesting feature of the leaves of the marram grass must be mentioned. "It may be noted on any breezy

day," says Prof. Bower,* smooth and convex surface

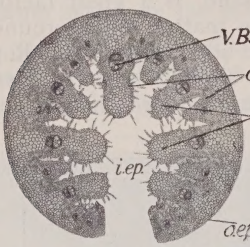


FIG. 169.—Transverse section through leaf of Marram Grass. *chl*, green mesophyll, communicating with air by stomata; *scl*, hard tissue (sclerenchyma); *i.ep.*, inner ("upper") epidermis; *o.ep.*, outer epidermis; *V.B.*, mid-rib. (× 15.) (T. D. Tuton Hall.)

"that the leaves present their to the wind, so that not only is their mechanical resistance to it the more effective, but also any sand it may convey glances off instead of catching in the grooves of the concave face."

Characters of sand-dune plants.—The plants which colonise the sand dunes include representatives of many different families, but they agree in being **xerophytes**, having leaves which are modified to restrict transpiration (the leaves of all dune grasses being, *e.g.*, folded or rolled so that the transpiring "upper" surface is inside). Although the plants have very long roots, their aerial parts do not grow to any great height above the surface of the ground, and in that way they escape as much as possible the drying effects of the constant wind, which are least marked close to the ground. Plants of the shifting dunes must also be able to grow rapidly upwards to the light after being covered with sand. Sand-dune plants have these characters in common, because without them they would be unable to survive the conditions.

Other plant formations.—The conception of the plant formation—so well exemplified by sand-dune plants—as *the whole community of plants living on a certain type of soil*, is extended to other habitats. Thus we recognise also the plant formations of salt marshes, siliceous soils (sands, clays and loams), calcareous soils (p. 110), moors, marshes, etc. Typically, a formation consists of a number of smaller unit groups, called plant *associations*. "Thus each of the types of vegetation—woodland, scrub and grassland—*within a given formation* is a plant association, and so is each definite phase in the primary development of a formation" (Tansley). We have seen such phases illustrated in the three associations of the sand-dune formation, and shall meet with others on pp. 295 and 300.

* *Plant Life on Land.* (Camb. Univ. Press.)

Plants of the seashore.—On the seaward side of the sand dunes the amount of sea-salt in the soil becomes the limiting factor, because only certain plants (called **halophytes** * for that reason) can tolerate salt in such quantities as occur here. Between the dunes and the usual high-tide mark may be found the sea rocket, the orache, the saltwort (Fig. 166, *S*) and the seablite—all annuals with **succulent leaves** and smooth waxy surfaces. These annual shore-plants are unable to grow upwards if covered by sand; their numbers are maintained by free seeding.

Fig. 170.—Glasswort (*Salicornia herbacea*), a characteristic halophyte. (After Schimper.)

The restrictions caused by the saltness of the soil become greater still in soil constantly saturated with sea water, as in salt marshes or mud flats. The marsh samphire or glasswort (Fig. 170) is common in such situations. Its leaves are minute, but its jointed branches are green and fleshy, and absorb rain-water or dew very readily. Still nearer the sea, and submerged at every tide, grows a curious monocotyledon called sea-grass, which has long, ribbon-like, floating leaves.

The heath association.—The term *heath* is given to areas covered with relatively poor and dry—usually sandy—soil containing in its surface layers a certain amount of peat. Typical heath is found at various heights from sea level up to 2000 feet. Upland heaths are called "moors" in the north of England and Scotland. Trees are usually absent from upland heaths, and the almost constant winds and the relative scarcity of water in the soil exclude most plants which are not xerophytic (p. 84). **The dominant plant** of heaths is usually the ling (common "heather," Fig. 172, *A*), but the bell or "Scotch" heather and the bilberry often occur with it. In the moister places the Scotch heather is replaced by the cross-leaved heath (Fig. 172, *B*).

* Greek, *halos*, salt.

The various species of "heather" closely resemble each other in manner of growth and the characters of their leaves, which are small, and folded or rolled up so that the stomata open into a chamber, in which the air is stagnant in spite of the surrounding high winds. Transpiration is thereby so restricted that the leaves can be retained safely even in winter, and the plants are evergreen. The bilberry has broad and thin leaves

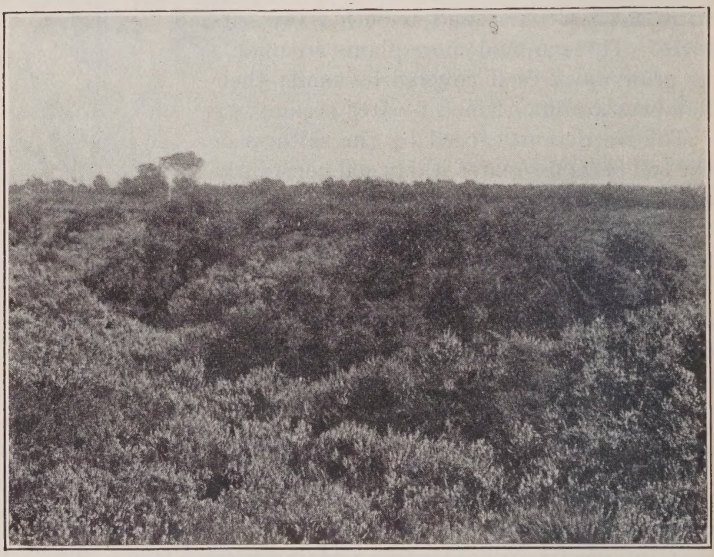


Photo. Flatters & Garnett, Ltd.

FIG. 171.—Gorse and Heather association.

which, in spite of their leathery character, transpire fairly freely in the summer. They are shed, however, before the approach of winter, when such leaves would be a danger to the plant (p. 85); and carbon assimilation is then carried on, without danger of excessive transpiration, by the green, ridged branches. A specially interesting fact is that the crowberry (Fig. 172, *C*)—which grows on the heaths and moors of some northern counties, and may be locally dominant—has leaves somewhat similar to those of the heathers, although it is not at

all closely related to these plants. Folded or rolled leaves are common also among the grasses growing on dry heaths. Sheep's fescue, mat grass, and wavy hairgrass show this character very well (Fig. 54).

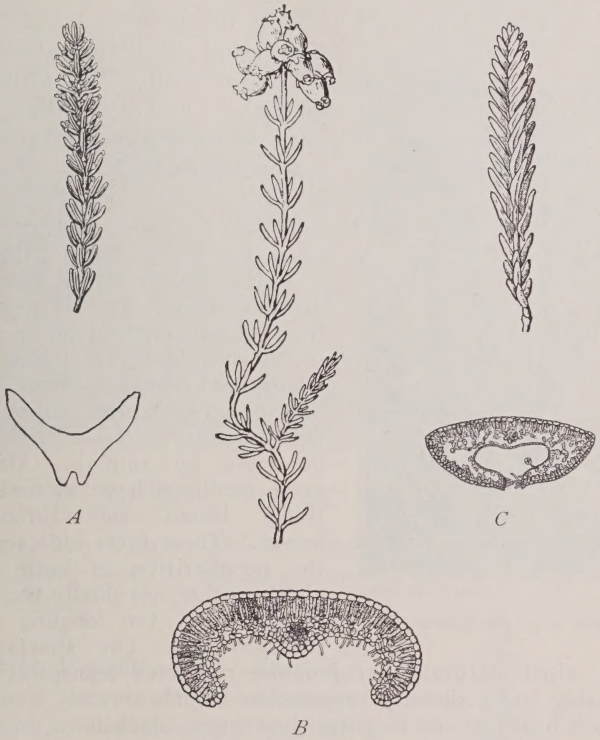


FIG. 172.—*A*, Ling. A leafy branch (× 6) and a cross-section of the base of the leaf, much magnified (both after Miall); *B*, Cross-leaved Heath, branch and magnified cross-section of leaf (both after Miall); *C*, Crowberry, staminate branch (after Miall), and magnified cross-section of leaf.

Gorse (furze or whin) is a common plant on heaths (Fig. 171), especially along roadsides and near villages. It is suggested by Prof. Weiss that ants (which often use human footpaths across heaths and are very fond of gorse seeds) are largely responsible for its distribution. However the

gorse has been introduced, it is very much at home on heaths. Its leaves are simple, narrow, and pointed (Fig. 173), and transpire but slowly; and its green, young branches, which are needle-pointed, do most of the work of food manufacture. The branches are strongly ridged, and the stomata on their surface are restricted to the grooves between the ridges, and are thereby protected from the wind. The skin (epidermis) is provided with a thick layer of waterproof and air-tight material (cuticle).

Photo. Henry Irving.

FIG. 173.—Dwarf Gorse.

It is often supposed that the gorse has become spiny because it is thereby protected from the attacks of animals. It has been found, however, that gorse grown in moist places, sheltered from winds, has branches without spines, and broader leaves, although it may be quite as liable as usual to be eaten by animals. Also, all gorse seedlings have at first relatively broad and three-lobed leaves. These facts indicate that the peculiarities, of both leaves and branches, are chiefly the result of the need for keeping down transpiration. The shortage of food, which naturally accompanies restricted transpiration, is probably more directly responsible for the prickly character of such heath plants as gorse, hawthorn, blackthorn, bramble, rose, etc. There can, of course, be no doubt that spines, thorns and prickles, however caused, do often protect the plants bearing them from animals.

While the common heather (ling) is dominant on the typical heath, it gives way largely to *bracken* and grasses, as well as many annual and ephemeral dicotyledons, on sandy and well-drained soils where the peat is thinner. Such a **grass-heath association** is often invaded by pine, which springs up

Photo. Flatters & Garnett, Ltd.

FIG. 174.—Upland Heath, merging into Birch and Oak woods (North Yorks.).
B Birches; *C*, Ling; *P*, Bracken; *Q*, Oaks; *V*, Bilberry.

wherever the winged seeds (p. 362) find room to germinate. The bilberry tends to replace the heather on the steeper slopes of the heath.

Moorland plants.—The essential difference between heath and true moor lies in the amount of **peat** in the soil. As the poor, sandy soil becomes moister and the peat deeper, the heath becomes a moor.

Such peat is largely the result of the accumulation, in past ages, of dead bog-moss (*Sphagnum*, Fig. 175), which is now a much less abundant plant. The peat on the wet upland moors of the

FIG. 175.—Leafy branch of Sphagnum, magnified. (After Miall.)

Pennines consists of the remains of the so-called *cotton grass*, which is really a sedge.* The cotton-grass association covers wide areas on the wet plateaux of the Pennines, Dartmoor, etc., where in summer the snow-white fruits of the cotton grass form a striking sight (Fig. 176). The peat in such places may be from 5 to 30 feet thick. The peat of the moors on the

Photo. Flatters & Garnett, Ltd.

FIG. 176.—Cotton-grass in fruit in a bog. The trees in the distance are Scots Pine.

Wicklow mountains of Ireland, in the north-west Highlands of Scotland, the Hebrides, and in Shetland, is chiefly formed by the *tufted clubrush* (deer's grass), another sedge.

The lower parts of these peat-forming plants die and accumulate as a sour, sodden mass, which does not decay

* Sedges (Fig. 131), like grasses (p. 169), have narrow, pointed leaves, but the leaves are three-ranked, the ligules are either very small or absent and the leaf-sheaths are not split. The flowers are often in spikelets with glumes, as grass flowers are. The stems of sedges are solid and triangular.

because free oxygen cannot penetrate it. The spongy peat thus formed retains most of the rainwater falling upon it, and forms **bogs** in many rainy mountain districts. Owing to the heavier rainfall, moors in Great Britain are almost restricted to the western part of the country, while heaths are commoner on the east.

The **lack of free oxygen** in sour peat soils not only prevents the activity of the organisms which in ordinary humus bring about decay and nitrification; it also limits the growth and vigour of roots, and therefore interferes with the plants' absorption of water. The curious result is that plants cannot live in wet peaty soils without some means of checking transpiration in order to avoid water-starvation; so that moorland plants are as markedly **xerophytic** as heath plants. Cotton grass has, for example, narrow, leathery leaves.*

As might have been expected, most of the typical plants of the heath occur also on the *drier parts* of the moors. Thus the bilberry and the heathers are common to both, and a mixed association of bilberry and ling covers large areas. Bilberry is almost always dominant on the well-drained and wind-swept ridges and summits, where the peat is shallow.† It is not found on the wettest part of the moor.

Ling is usually the dominant plant on the *gentler* slopes of the moor where the peat is relatively shallow and dry, but gives place to the cross-leaved heath where the peat is equally thick but less dry. In these *wetter parts* of the heather moor are found in greatest abundance those insectivorous plants the sundew and the butterwort (p. 231)—which make up for the lack of nitrogen salts in the soil by catching and digesting insects—as well as various large rushes, the sweet gale, and other bog plants. Sweet gale becomes dominant on parts of the wet heather-moor where the soil water is fairly free from peat acids.

* The rhizomes and roots of the cotton grass are supplied with oxygen by air-channels communicating with the leaves.

† Associations of bilberry are almost entirely absent from the North West Highlands of Scotland, from the Hebrides, and from the Shetland Islands. (Tansley.)

Grass moor.—Grasses of different kinds—especially mat grass, sheep's fescue and the wavy hair-grass (Fig. 54), with the purple moor-grass in the wetter places—grow to varying extents on the moors, and one or other is often dominant.

Photo. Flatters & Garnett, Ltd.

FIG. 177.—Grass Moor Association, consisting of Purple Moor-grass, Bilberry, Bell Heather, Ling, and Cotton-grass.

Nearly all (like sand-dune grasses) are able to restrict transpiration by means of rolled or folded leaves. Gorse and bracken, so common on grass heaths, are absent from grass moor.

Fenland.—The peat soils of East Anglia are very different in character from those of moors; for the water they contain is rich in mineral salts (especially salts of lime) and, so far from being sour, is alkaline (the reverse of acid). Such areas form fenland. The vegetation of fens is not xerophytic, but is very similar to the marsh association described on p. 292. The alder is the dominant tree of fenland.

34. PLANT FORMATIONS OF SILICEOUS AND CALCAREOUS SOILS.

Types of woodland.—Trees are generally absent from heaths and moors. An upland heath (Fig. 174), however, often merges into birch or pine-woods at a height (in Great Britain) of about 1500 feet. These in turn are replaced by oak woods (Figs. 178 and 179) at lower levels on siliceous (sandy and clayey) soils. On calcareous soils (those containing a great deal of chalk or limestone), beech and ash are the commonest woods; while on sandy limestone and marl (clayey limestone), mixed woods of oak and ash are found. On the undrained soils of flat and marshy country, as well as of the borders of lowland moors, alder and willow are the dominant trees.

The woodlands of siliceous soils.—The special difficulty experienced by most plants of the undergrowth of woods is the scarcity of light caused by the thickness of the foliage above. Obviously this difficulty will vary in degree with the kind of tree mainly composing the wood, and also with the season.* In **evergreen woods** with closely growing trees, the light is dim at all seasons, and no green plants except a few kinds of moss may be able to grow on the ground. Moreover, the lower branches of such closely growing trees are too much shaded to bear healthy leaves, and they themselves die and fall off, leaving the long straight trunks so characteristic of pine and fir woods.

The foliage of the **birch** (p. 448), on the other hand, is so open that even in summer, when the leaves are most abundant, it does not seriously deprive the undergrowth of light. In birch woods on the edge of a moor, heather and bilberry are naturally dominant on the "wood-floor." Birches on more sandy soils are commonly associated with such shrubs as gorse and bramble (blackberry), while bracken, wavy hair-grass, tormentil, heath bed-straw and wood-sage grow between the shrubs, and mosses clothe the ground.

*The intensity of light can be roughly compared by timing the exposure needed to darken sensitive photographic paper to a standard tint. Simple "actinometers" on this principle can be obtained from dealers in photographic materials or can be easily devised.

Stratification of woodland plants.—We are thus able to recognise three or four *different levels of foliage* in birch and many other woods. The trees, shrubs and low-growing herbs are not necessarily antagonistic; the tall plants often afford indispensable shelter, shade or other advantages to the shorter and more delicate species. A similar state of things is found in hedges, and in the reed-swamp association of ponds, etc. (p. 291). A particularly interesting case of *stratification below ground* is

Photo. W. B. Crump.

Fig. 178.—Oak Wood in Spring, with carpet of Bluebells. The grass is Soft-grass. *B*, Broom.

common in oak woods (Fig. 178), where soft grass, bluebells and bracken fern come up in turn in the same place. This is made possible by the fact that the grass roots are just below the surface, the bracken rhizomes under them, and the fully developed bluebell bulbs deeper still (p. 211). Here again, convenient differences in habit and needs free closely associated plants from competition with one another.

Oak woods are of two main types: (1) an upland type usually referred to as the "dry oak wood" (consisting chiefly of the "sessile-fruited" variety of oak, with long-stalked leaves,

Fig. 327), which is found commonly on well-drained *sandy* soils at heights of 500 to 1000 feet; and (2) a lowland type called the "damp oak wood" (in which the oaks are mostly

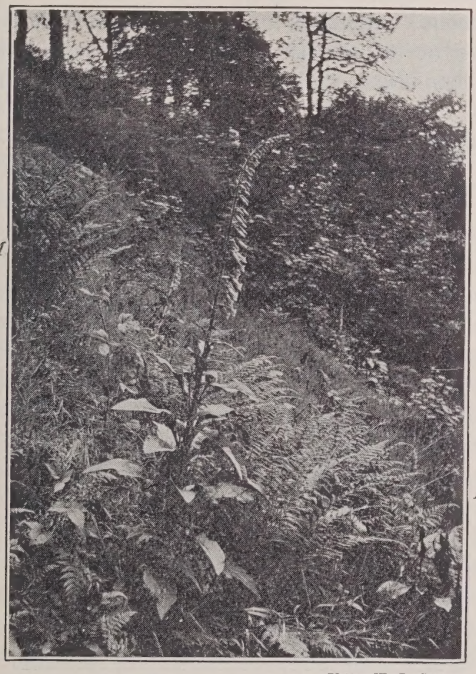


Photo. W. B. Crump.

Fig. 179.—Oak Wood with Summer Undergrowth: Foxgloves, Bramble (to the left of the near Foxglove), Male Fern (*M*), Lady Fern (to the left of the letter *L*). The grass growing obliquely upwards from the letter *L* is mostly Soft-grass, but partly Hairy Brome.

"pedunculate," with short-stalked leaves, Fig. 293), occurring on more *clayey* soils.

Dry oak-woods admit less light than birches growing equally closely, but quite sufficient to support an abundant undergrowth. Gorse, ling and bracken are common in the more elevated and dry oak woods, as they are in birch woods, but are replaced by holly, wild rose and bramble at lower levels, where such herbaceous plants as foxglove, anemone, bluebell (wild hyacinth),

sheep's sorrel, golden rod and soft-grass (Fig. 178) add themselves to the few species found in the higher birch woods.

In a **damp oak-wood** the canopy of foliage is usually thicker, and the shade therefore deeper, than in the drier type; and the herbaceous undergrowth consists more definitely and exclusively either (*a*) of "shade plants" (such as sanicle, wood sorrel (Fig. 180), sweet violet, wood geranium, woodruff), which,

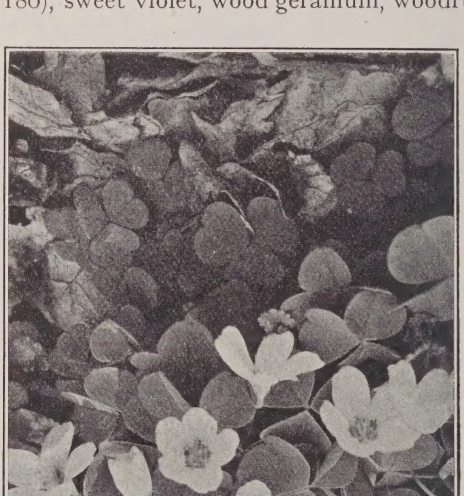


Photo. Henry Irving.

FIG. 180.—Wood Sorrel, a typical shade plant.

as there is no danger of excessive transpiration, are able, by means of large and thin leaves and long internodes, to make the most of weak light, or (*b*) of plants which—requiring a good light for carbon assimilation and the visits of insects to the flowers—produce their leaves and flowers in early spring, before the trees above are in full leaf. Snowdrop, lesser celandine, wood anemone, primrose, bluebell and broad-leaved garlic (mentioned roughly in order of flowering) are good examples of woodland plants which perforce accomplish most of the season's food-making before the majority of plants have started work.

The underground food-stores which such plants possess (Chap. XII.) enable them safely to appear above ground even in the most inclement weather of early spring. Many woodland flowers which come out later (*e.g.* woodruff and honeysuckle) attract insects by strong scent. Common grasses of the damp oak-wood are hairy brome, false brome, wood melick, etc. The bracken of the dry oak-wood has given place to the male-fern (p. 467) and various other ferns. The commonest shrub here is the **hazel**; others are hawthorn, alder, bramble, wild rose, elder, honeysuckle, and holly.

Woodlands of calcareous soils.—The commonest woods on soils containing much chalk or limestone are beech and ash associations. **Beech-woods** are most abundant on the chalk downs. *Where beeches grow at all closely* their perfect leaf-mosaic (Fig. 330) casts so dense a shade that the only green plants which can exist beneath them are a few shade-enduring species (*e.g* wood sorrel, sanicle, etc.). The " bird's nest " and bird's nest orchid—flowering plants which have no chlorophyll and feed entirely on decaying vegetation (p. 233)—are, however, not uncommon in the deep humus, while fungi (p. 478) often become conspicuous in autumn. *Where the trees are farther apart,* and at the edge of the wood, there is often sufficient light for a fairly abundant undergrowth. **Yew** trees often occur under the beeches; and dog's mercury (usually dominant), sanicle, violets, wild strawberry and enchanter's nightshade are common on the ground.

Ash woods flourish typically on the limestone hills (much older, geologically, than chalk) of the north and west of England, where the rainfall is greater. Ash trees (p. 433) do not cast deep shade, and the undergrowth is therefore abundant. Wych elm, hawthorn and hazel are characteristic shrubs of the ashwood association, though several others occur; while in the moister places broad-leaved garlic, lesser celandine, wood anemone, red campion and wild strawberry, and in the drier spots stretches of ground-ivy and a specially interesting " society " of dog's mercury and moschatel, are common.

Calcareous and siliceous scrub.—Most of our scrub seems to have been formed by the degeneration of woodland; but a

" progressive " scrub, which has been formed by the invasion of grassland by **shrubs**, is met with locally. Scrub shows every transition between the woodland and the grassland of the same formation, and therefore includes the shrubs already mentioned as occurring in the woodlands. Some of these (*e.g.* hawthorn and sloe) are common to siliceous and calcareous soils. On the other hand, species of wild rose are notably abundant among the chalk scrub, while the various kinds of bramble are commoner on sandy soils. Other species of shrubs and climbers abundant on chalk are clematis, spindle tree, buckthorn, juniper, dogwood, elder, wayfaring tree, white bryony, privet, spurge laurel, etc.* Several orchids, specially characteristic of the chalk, shelter beneath the shrubs.

Grassland of calcareous and siliceous soils.—*Sheep's fescue* is the dominant grass of the chalk grassland association (the pasture of the chalk downs), as well as of limestone grassland. Associated with it are other herbaceous plants which are absent from or rare on siliceous soils. Among these the following are mentioned by Dr. C. E. Moss † as widespread and characteristic of **calcareous grassland**:—small meadow rue, hairy dog violet, chalk milkwort, lady's fingers, horseshoe vetch, salad burnet, spring cinquefoil, a rockrose, mountain bedstraw, squinancy wort, small scabious, a hawksbit, clustered bellflower, marjoram, hoary plantain, several orchids, two species of wild oat, koeleria, upright bromegrass, and false bromegrass.

On the other hand, Dr. Moss points out that " the two principal grasses (mat grass and wavy hair grass) of the drier type of **siliceous grassland** are quite absent from calcareous grassland, and so is the principal grass (purple moor grass) of the wetter type of siliceous grassland. The bracken, gorse, and the common rushes which bring about such a characteristic facies of the siliceous grassland, are only of local occurrence on calcareous grassland. . . . Many other plants characteristic of the

* Notice that our woodland shrubs—in contrast to forest *trees*—almost invariably have insect-pollinated flowers and bird-dispersed fruits.

† *Types of British Vegetation,* edited by A. G. Tansley (Camb. Univ. Press).

siliceous grasslands are also absent from calcareous grasslands, and the following list is a selection of the more widespread of these: red sandwort, heath milkwort, broom, petty whin, creeping tormentil, heath bedstraw, heath cudweed, sheep's-bit, bell heather, ling, bilberry, foxglove, common cow-wheat, crowberry, creeping willow, a spotted orchis, heath wood rush, green-ribbed sedge, soft grass, hard fern."

35. PLANTS OF THE HEDGEROWS.

Plants of the hedgerows.—The difficulty of the light-supply, which has been seen to account for the chief peculiarities of the ground flora of woods, is also responsible for some of the most interesting features of hedgerows. It is necessary to distinguish between (1) the hedge itself, which is usually composed of specially planted bushes or shrubs, and (2) the hedgebank, which slopes steeply down to the level of the field or roadside.

The hedge proper.—This is commonly composed of hawthorn, hazel, willow, bramble, blackthorn (sloe), hedge maple, holly, or other small trees or bushes. In many cases it is trimmed regularly, and a dense growth is thereby promoted (p. 151).

The hedge-bank.—The chief ecological interest of the hedgerow, however, lies in the bank.

A. **The top of the bank** is usually dry, and is deeply shaded by the thick growth of the hedge above. Naturally, the only herbaceous plants which can flourish in such a situation are (*a*) climbers which are able to raise themselves to the light by the aid of the twigs of the shrubs of the hedge proper; (*b*) plants able quickly to produce long, self-supporting stems; or (*c*) "shade plants," which are adapted—by large, thin leaves, or by much-divided leaves admitting light to their lower parts—to make the most of feeble illumination.

(*a*) Among the **climbers** common in hedgerows are (i) such *scramblers* as bramble, wild rose, and goosegrass (cleavers); (ii) *plants with twining stems, e.g.* bindweed, hop, honeysuckle, bittersweet, and "black bryony" (*Tamus*); (iii) *tendril climbers*

such as vetches, white bryony, and (on chalky soils) clematis or traveller's joy, which climbs by sensitive twining leaf-stalks (Chapter XI.).

(*b*) The plants which are able to exist at the top of the hedge-bank because they have long and quickly growing **erect stems**, and can so lift their leaves out of the shade, include the stinging nettles, the various dead-nettles and other Labiatae, hedge-mustard, garlic mustard, stitchworts, thistles and teasel.

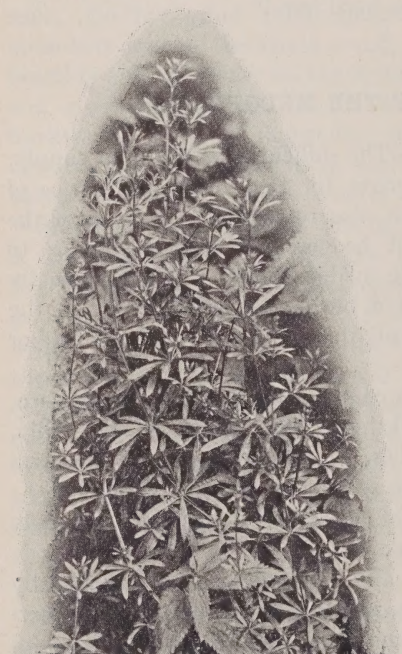


Photo Henry Irving.

FIG. 181.—Cleavers (Goose-grass) climbing up nettles, etc., in a hedge.

(*c*) The following **shade plants**, among others, may be found at the tops of hedge-banks: (i) *with undivided leaves*, broad-leaved garlic, sandwort, arum, wild basil, enchanter's nightshade, foxglove, dog's mercury, ground-ivy, primrose, greater stitchwort, germander speedwell, sweet violet and dog violet; (ii) *with divided leaves*, moschatel, wild chervil, herb Robert, goldilocks buttercup, and (in moist places) various ferns.

B. On **the slope of the bank**, where the light is abundant, *prostrate plants* (*e.g.* chickweeds and creeping cinquefoil) and *rosette plants* (*e.g.* plantains, dandelion, daisy, hawkweeds and shepherd's purse), as well as grasses and other erect plants are common.

Where one side of the hedge is much better lighted than the other (*e.g.* when the hedge runs east and west) it may be observed that the shaded plants grow more sparsely, have

larger leaves, and are taller and of more "weedy" appearance generally, than those of the same species on the sunny side.

It will be noticed that the typical vegetation of hedgerows resembles that growing on the edges of woods. This is easily

Photo. Henry Irving.

FIG. 182.—Hawthorn hedge almost smothered in Black Bryony (*Tamus*) and Bramble.

understood when it is remembered that plants of both situations suffer from the same disadvantage, viz. a restricted light-supply. Hedgerow plants, however, form a very heterogeneous collection, and consist largely of native species which have been debarred from the neighbouring cultivated land.

At the foot of a hedge-bank is often a ditch. The plants growing in it are of the marsh or aquatic types to be described in the next section.

36. PLANTS OF PONDS, STREAMS, AND MARSHES.

One of the most interesting ecological exercises is to trace the changes in plant form found on passing from the deep water of a shelving pond or stream, through the swamp and marsh of the margin, to the meadowland beyond, and to explain the peculiarities of the vegetation in terms of the environment.

Photo. Henry Irving.

FIG. 183.—Yellow Water Lily.

Deep-water plants.—In stagnant water the plants growing farthest from the bank are often **floating forms** with no attachment to the bottom. Among flowering plants of this group are duckweed and frog-bit (which have surface-floating fronds and hanging roots) and bladderwort (Fig. 151), with finely divided fronds and entirely submerged, excepting the flowering shoots. Such plants are of course absent from streams, except among the rooted plants near the shore, where they can find shelter from the current.

Marginal associations.—The marginal associations occur in more or less well-marked **zones**, as the water becomes increasingly shallow towards the bank. Deepest of these is (*a*) the zone of rooted plants which are entirely submerged (*e.g.* various species

of *Elodea*, Fig. 50). As soon as the water becomes shallow enough, appear (*b*) rooted forms which can raise their flowers and in most cases some, if not all, of their leaves to the surface, though their stems are submerged. In this zone typical examples are the water milfoil, in which all the leaves are submerged and only the flowers appear above the surface; the water buttercups (Fig. 188), arrowhead (Fig. 187), and the water

Photo. Flatters & Garnett, Ltd.

FIG. 184.—Reed-swamp. Lake reed (*Scirpus lacustris*) and Bulrush (*Typha*). The trees in the background are Alder and Willow.

starwort, which have some leaves floating and others submerged; and the white and yellow water lilies (Fig. 183), nearly all the leaves of which are floating.

Shoreward, the *reed-swamp association* succeeds the "floating-leaf" plants. The reed-swamp association consists chiefly of tall monocotyledons of social habit, with long, narrow, erect leaves; only the roots, the long horizontal rhizomes, and the lower part of the unbranched erect shoots, are under water. In the reed-swamp association, three zones are usually to be

distinguished, viz. (*c*) a belt of lake-reeds and bulrushes (often with mare's-tail) towards the open water (Fig. 184), (*d*) an intermediate zone of common reeds (*Phragmites*), and (*e*) on the landward side a fringing band of rushes, sedges, horsetail, spearwort buttercups, watercresses, water dock, etc.

Photo. Henry Irving.

FIG. 185.—Marsh Vegetation. The plants noted were Branched Bur-weed, Osier Willow, Marsh Stachys, Mint, Forget-me-not, Willow Herb, Polygonum, and Grasses.

Marsh plants.—At its edge the swamp often passes into marsh or wet meadow. Here the soil may be saturated, but is not actually covered, by fresh * water; so that only the roots and rhizomes of the plants are submerged. In addition to many of the swamp plants already mentioned, the marsh contains such *perennial plants* as burweed, meadowsweet, marsh marigold, ragged Robin, marsh mallow, water mint, marsh forget-me-not, etc. (Fig. 185); and in the drier parts a number of *annuals* (*e.g.* bur-marigolds, water purslane, celery-leaved

* Contrast the sour peat-water of bogs (p. 279).

buttercup, etc.) spring up. Alder and willow are the trees most typically associated with marshy soil (Fig. 184).

Hydrophytes: their advantages and disadvantages.—To explain satisfactorily the respective peculiarities of these zones of plants, it is necessary to consider what special advantages and disadvantages growth in various depths of fresh water entails. One great danger besetting all hydrophytes * or water plants is drowning, that is, suffocation from **lack of oxygen.** Sour bog-water and foul water containing much organic matter soon become devoid of free oxygen, and even fresh water does not contain more than $\frac{1}{2}$ per cent. by volume. The oxygen which the roots of ordinary land plants need for respiration is taken from the free air present in the soil. Where the soil is water-logged, as in bogs and marshes, some other method of aerating the roots is plainly necessary. This is provided by a system of intercellular air-spaces (Fig. 186) extending from the leaves through the stems into the roots. By means of these channels oxygen (formed during photosynthesis) can get to all parts of the plants. So abundant are the air spaces that the whole plant feels quite spongy when pressed between finger and thumb.

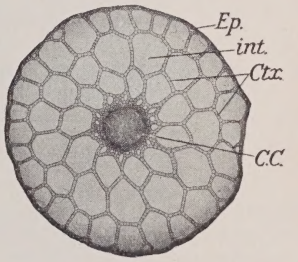


FIG. 186.—Photomicrograph of transverse section of stem of Marestail. *Ep.*, epidermis; *Ctx.*, cells of cortex; *int.*, intercellular space in cortex; *C.C.*, central cylinder. (× 2½.) (T. D. T. Hall.)

In plants growing actually in water, the internal air spaces tend to float up the stems and leaf-stalks, so that they need scarcely any strengthening material to keep them erect. Such plants require very little wood (p. 98), for the further reason that water can be absorbed by any part of the submerged surface, and not merely by the roots. Any strengthening material which does occur forms a core near or at the middle of the stem (where it is best able to withstand the pull of any current), instead of near the outside as is usual in erect herbaceous land-plants (p. 167).

Submerged plants growing in the deep water suffer, in proportion to the depth of the water, from **lack of light**, and show the long internodes usual in shaded plants.

* Greek, *hudor*, water.

Lowland ponds and streams in general are rich in dissolved salts without containing an injurious excess, and also in dissolved carbon dioxide, so that plants living in them grow vigorously and branch freely; they are nearly all perennial, flowering is comparatively rare, and **vegetative propagation** often takes the place of seed production. Many mountain lochs on the contrary contain so little material in solution that very few plants are able to grow in them.

Even aquatic plants are unable to absorb water in the coldest weather of winter, but at this time they do not expose any

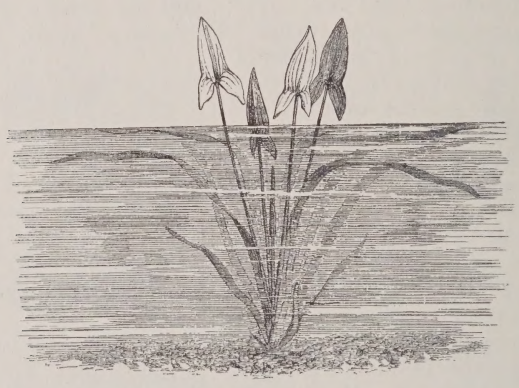


FIG. 187.—Arrowhead, with sagittate aerial leaves and ribbon-shaped submerged leaves. (After Figuier.)

transpiring organs to the air. Most of them survive the winter by means of rhizomes, corms, or special resting buds, which lie buried in the mud. At other seasons the air surrounding the leaves of swamp and marsh plants is so saturated with moisture as to render **transpiration difficult.** Some means of getting rid of excess water is, of course, necessary to raise the needed mineral salts to the aerial leaves, and many such leaves actually give it off in the form of liquid drops (p. 82).

If **plants growing in running water** possessed submerged leaves of the ordinary type, the leaves would be in danger of being torn, and the whole plant of being uprooted, by **the force of the current.** It is interesting to find that *submerged leaves* are usually narrow and ribbon-shaped (water plantain, arrowhead (Fig. 188) and—in deep water—yellow water lily), or cut up into thread-like filaments (water milfoil and water buttercups). Such leaves trail out into the current, to which

they offer a minimum of resistance, and at the same time expose a relatively enormous surface for absorption of dissolved carbon dioxide, etc. They have no stomata. On the other hand, *floating leaves* have entire or lobed margins

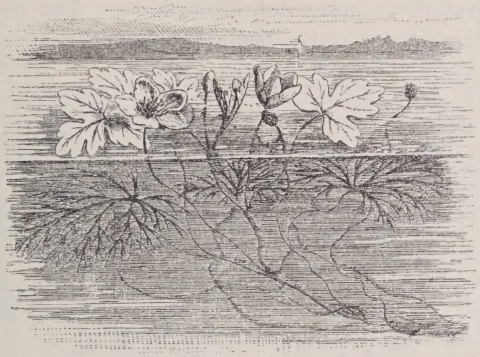


Fig. 188.—Water Buttercup, with lobed floating leaves and filamentous submerged leaves. (After Figuier.)

(water buttercup) and are often more or less circular in shape (water lilies, Fig. 183). Their stomata are restricted to the upper surface. In swiftly flowing streams, not only free floating plants, but also rooted plants with floating leaves, are of course absent.

From reed-swamp to forest.—Among the plants of the reed-swamp association an accumulation of old leaves and other plant-remains gradually forms, and this in its turn tends to entangle material of any kind which is drifting about in the water. The new soil which is thus collected makes the edge of the pond or stream shallower; the marsh plants invade the reed zones, and the reeds creep further towards the middle. By a continuation of this process the pond is filled up, and its place presently occupied by meadow-land, which (if ungrazed, so that tree seedlings can survive) will be replaced in turn by forest; alder, willow and birch acting as pioneers in wet soil (Fig. 184). In the river valleys of East Norfolk every stage in a somewhat similar development of fen (p. 280) from reed-swamp may be found.

37. MEADOWS AND CORNFIELDS.

Weeds in general.—A weed is a plant which is regarded as a nuisance, usually because it interferes directly or indirectly with the growth of more desirable plants. The marked biological efficiency of weeds, shown by their persistence in spite

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FIG. 189.—Perennial Rye Grass.

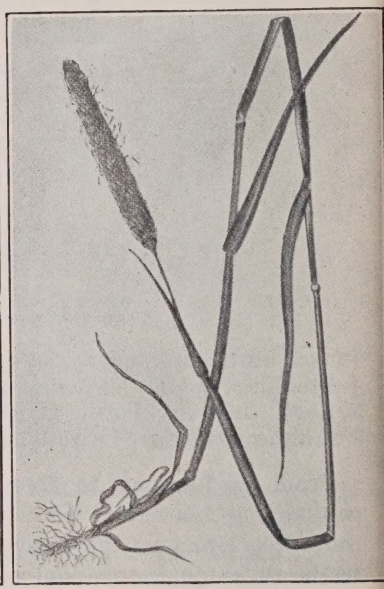

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FIG. 190.—Meadow Foxtail.

of human efforts to extirpate them, makes these plants the most generally instructive to students of botany.

Meadow land and pasture.—The **plants encouraged** in meadows are of course perennial fodder grasses, notably perennial rye grass (Fig. 189), meadow foxtail (Fig. 190), meadow fescue (Fig. 191), timothy, smooth brome grass, etc., together with certain Leguminosae, especially clovers (Fig. 192).

With them grow certain **weeds** which vary according to soil, the extent to which the field is grazed or mown, the method of manuring, etc. The condition of their success is that they

must be able to compete with the grasses, etc., among which they grow. Thus they are nearly all **perennials**, and forms are common which (by keeping pace in rate of growth, and by means of leaves which are either long, narrow, and erect, or much-divided) can avoid being seriously hampered by the close crowding of surrounding grasses. Examples are sorrel, bitter buttercup, ox-eye daisy, ribwort plantain. Other weeds

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FIG. 191.—Meadow Fescue. See also Fig. 311.

escape the crowding, as well as destruction by the scythe, by forming rosettes of leaves pressed close to the ground, by flowering whilst the grass is still short (daisy, dandelion, bulbous buttercup), or by flowering after haymaking is over (yarrow, autumnal hawkbit, scabious, knapweed). The most objectionable weeds are ragwort, thistles, docks and sorrels, cranesbills, wild carrot, Yorkshire fog and soft brome grasses, and dodder (in clover). Where the meadow is on sour, damp soil, rushes, sedges and horsetails become frequent.

The **weeds of a lawn** are chiefly perennials (*e.g.* daisy, plantains (Fig. 193), dandelion, yarrow, creeping buttercup, etc.), which, having rosettes of leaves lying flat on the ground, and contractile roots, are not seriously injured by the mower and roller.

Photo. Henry Irving.

FIG. 192.—White Clover, a valuable fodder plant.

Weeds of arable land.—Only in places from which perennials in general are excluded can annuals obtain a favourable footing. Most of the weeds which infest regularly ploughed or dug land are, as might be expected, **quickly growing annuals** or ephemerals, which depend for persistence upon efficient seed dispersal; for the plough or spade effectually destroys the great majority of perennial weeds, though it may help to spread others (creeping thistle, dandelion, lesser bindweed, couch, horsetail). The commonest of the short-lived weeds are annual meadow grass, shepherd's purse, groundsel, chickweeds, poppies, charlock, field speedwells, etc.

In cornfields many of the weeds overgrow and smother the

corn, having for the most part narrow leaves; and they may ripen their seeds at the same time as, and be sown with, the corn. Such are charlock, poppy, corn crowfoot, corn-cockle (Fig. 255), and spurrey. Other weeds, sheltered by the tall plants, grow close to the ground (*e.g.* chickweeds, speedwells, hop trefoil, etc.), or climb up them (lesser bindweed (Fig. 122) and climbing polygonum or black bindweed).

Fig. 193.—Hoary Plantain, a common weed of neglected lawns.

The colonisation of new ground.—The student should take every opportunity of studying the order in which plants occupy newly exposed ground (railway embankments, rubbish tips, abandoned building sites, mole-hills, etc.). Mosses, lichens and other spore-distributed plants (Chap. XXI.) come first. The flowering plants which next gain a footing (by seed dispersal) are naturally such ephemerals and annuals as are common in the neighbourhood. For a time there is ample room for all comers, but the number of species is small. These pioneer plants form what is called an **open** community. Presently a stage is reached when enough humus has accumulated to allow perennials—the order of their arrival depending on their means of dispersal—to seize the ground and oust the annuals because, as perennials, they store underground food supplies. The success of the perennials is sometimes apparent even in the second year after the new ground has been exposed. The number of competing species in this **intermediate stage** is large, and the ground is fully occupied. The "life forms" are for some time diverse, seeing that as yet there is no standard habit of growth to be competed with; and various grasses, thistles, docks, willow herbs, plantains, ragwort, coltsfoot, dandelion, creeping buttercup, teasel, dead-nettles, etc., struggle for existence. At length certain of the competing species are beaten

and die; the most successful become dominant, and the character of the vegetation becomes relatively stable. In other words, the association is **closed.**

Succession of plant associations.—Such a "closed" association is not necessarily permanent. There is a tendency—in soils with a sufficient water supply (p. 172) for herbaceous perennials to be invaded by bushes (scrub), and for scrub to become woodland. Indeed, woodland seems to be the "climax" association,

Photo. T. A. Jefferies.

FIG. 194.—Stretch of bared rock invaded by Wavy Hair Grass (*Deschampsia flexuosa*), which gradually forms a sward and starts a new cycle of vegetation.

and there is no doubt that the greater part of the British Isles was occupied by forests before man interfered with the natural distribution of the vegetation. His destruction of the forests led to the formation (*a*) of moors in the wetter parts of the country, (*b*) of heaths on poor sandy soils, and (*c*) of grassland (pasture or arable land) on the more fertile soils. As grassland left to itself will usually undergo **regeneration** to woodland, so some barren heaths also are invaded by trees, as we have seen (p. 276).

On the other hand, many cases are known of **retrogression,** where woodlands—especially on sandy soils—"degenerate"

to scrub and, later, to grassland. A striking instance of retrogression is seen in the remains of ancient forests of birch and pine which have been found buried in thick peat deep below the surface of certain British moors. Evidently the forests were invaded by peat-forming plants, until the accumulation of sour bogs gradually made tree growth impossible. In some parts of Britain a still later stage is found, in which the peat itself, which destroyed the forests, has been removed by rain and wind. The bare rock thus exposed is now being colonised once more by plants (Fig. 194), and the whole cycle of changes will no doubt be repeated.

EXERCISES XV.

1. Describe, with the aid of a sketch-map, the natural vegetation of any small area which you have studied, and name the characteristic plants. (C.J.)

2. What is a plant association ? Show how you would proceed to study a plant association in the field, and state the kinds of deductions you would draw from your observations. (N.F.U.)

3. Describe the vegetation of a sand dune. Mention the most striking characteristics which fit plants to live in such a situation. Draw three plants which commonly occur on sand dunes in Great Britain. (L.M.)

4. Explain the botanical significance of the planting of Marram grass (*Psamma* or *Ammophila*) on sand dunes. (C.S., part question.)

5. Describe the effects of salt water upon (*a*) a single plant cell and (*b*) general vegetation, as seen, for example, in a salt-marsh. Account for these effects as far as you can. (L.M.)

6. What are the chief characteristics of vegetation growing on a light sandy soil ? Account for these characteristics as far as you can. (L.M.)

7. Write a short account of the vegetation of *either* a sandy heath *or* a salt marsh. Describe *three* plants growing in the situation you select, with special reference to any peculiarities by which they are fitted for their habitat. (O.S.)

8. Describe the vegetation of a stretch of sand dunes *or* a moor, pointing out how the conditions of the environment affect the form and structure of the plants composing the vegetation. (L.M.)

9. Give some account of the plants you would expect to find in a bog, mentioning any peculiarities they exhibit which can be correlated with their habitat. (J.M.B., Hr. Sch. Cert.)

10. What is a xerophyte? Explain why the plants of peat bogs need to economise their water supply.

11. Mention the names of three common trees which are characteristic of different types of English woodlands, and give a brief summary of the characters by which you would recognise each during the winter. (C.S.)

12. In a district whose main geographical features were known to you, where would you look for pines, oaks, beeches, and alders? How would you distinguish between these trees in summer and winter? (J.M.B., Sen. School Exam.)

13. "Viewing a wood as a plant community, each constituent plant can be regarded as having some effect upon the growth or development of other plants." Comment upon this. Classify the growths which occur in an English forest. (Cert.)

14. Name *four* flowering plants you have found growing near the sea-shore. State in each case exactly where it was growing, and with the aid of diagrams describe any peculiarities which you think may be connected with its habitat. (O.S.)

15. Describe *three* herbaceous plants which you have found growing in a wood, and state the month in which you have found them in flower.

16. Give an account of the flora of a wood. Select any four plants of the undergrowth which show special adaptations to the conditions of their habitat, and describe these adaptations in each case. (L.M.)

17. How do (*a*) the woodlands, (*b*) the scrub, (*c*) the grasslands of calcareous soils differ from those of non-calcareous soils?

18. Explain why early-flowering plants are common in woods, and climbing plants common in hedgerows.

19. Name *ten* plants which are commonly found growing together in hedgerows. In each case state the month in which you would expect to find (*a*) the leaves appearing, (*b*) the flowers opening.

If the hedge runs from east to west, what differences would you expect to find in the leaves of the plant growing on the north and south sides respectively? (L.M.)

20. What plants would you be likely to meet with in summer in *one* of the following situations: (*a*) a heather moor, (*b*) a hedgerow? (J.M.B., Sen. School Exam.)

21. What observations have you made of plants growing *either* (1) on sand dunes *or* (2) in and around a pond *or* (3) on a moor? Your answer should deal with only *one* of these localities. (Prel. Cert.)

22. An ordinary herbaceous plant is unable to grow in soil which has become saturated with water. Explain how an aquatic plant is able to flourish in a similar situation. (C.S.)

23. In what respects do the leaves of water plants differ from those of ordinary land plants? Illustrate your answer by examples, and state how you account for the differences.
(J.M.B. Matric.)

24. What mineral salts are absorbed by ordinary roots? Give a drawing of the parts concerned. What is the process involved? In what respects do submerged aquatic plants differ?
(L.L.A.)

25. Give the main characters of any green water plant you have studied. In what respects does it differ from land plants and how are these differences connected with the obtaining of mineral food, oxygen and carbon dioxide? (J.M.B. Matric.)

26. Enumerate in order, the chief plant-forms occurring between the middle and the margin of a pond with sloping banks.

27. Mention some of the characteristics of the vegetation of a pond or river. Give an account of *one* pond or river plant, and explain any features in which the plant is specially adapted to its surroundings. (J.M.B. Matric.)

28. Write a short account of the vegetation of a pond or slowly running stream. (C.P.)

29. Enumerate the wild plants you have found growing along the margins of rivers, ponds, and lakes. Distinguish between those which grow with their leaves (*a*) wholly in the air, (*b*) partly in the air and partly in the water, (*c*) wholly submerged.
In each case mention the state in which the plant exists during the winter. (L.M.)

30. Describe *four* plants you have found growing wholly or partially submerged in water, and draw attention to any peculiarities which can be explained by their mode of life. (O.S.)

31. Give an account of the botanical characteristics of the plants commonly found growing in *one* of the following habitats:
(*a*) a sand dune or salt marsh,
(*b*) a damp woodland on clay soil,
(*c*) the margin of a fresh-water stream.
In the case you select explain how far these characters may be considered to show adaptation of the plants to their habitat. (C.S.)

32. Give an account of the vegetation in a pond, *or* on the ground in a wood, which you have examined. Give some account of the plants as they are found in winter, in spring, and at midsummer. (J.B.M. Hr. Sch. Cert.)

33. Describe with sketches how plants of any *two* of the following types obtain the materials necessary for growth :

(*a*) submerged water plants,
(*b*) epiphytic plants,
(*c*) parasitic plants.

Name *two* examples of each of the types you describe. (C.S.)

34. Some children are taken, at the end of May or early in June, for a Nature walk down a lane bordered by high hedge banks, and across a meadow, in one corner of which is a good-sized pool with a marshy edge. Name six plant specimens which they might bring home from such a ramble, and say what use you could make of these specimens during the next week's Nature lessons. State the age of the children for whom the work would be suitable. (N.F.U.)

35. Give examples of different plant associations occupying in succession the same situation.

36. Contrast as plant habitats (*a*) a marsh and a bog, (*b*) a heath and a moor. How are the differences reflected in the plant associations occupying them ?

37. Describe any peculiarities of structure in one of the following plants, and show how they enable it to overcome the difficulties of its ordinary habitat : Marram grass, bluebell (wild hyacinth), gorse, cotton grass, water buttercup.

38. Mention *five* plants which you have found as common weeds of cultivated ground, and describe in each case any peculiarities which you think may be connected with its prevalence as a weed. (O.S.)

39. State the general differences between the weeds of a cornfield and those of a meadow. Name six common plants from each habitat. (N.F.U.)

40. In what situations are (*a*) annuals much commoner than perennials, (*b*) perennials much commoner than annuals ? Explain the facts.

41. " The most abundant weeds of meadows and pastures are perennials, but arable land is well adapted to the requirements of annual weeds." Discuss this statement and set out what evidence you can in support of it, at the same time mentioning any annual weeds you have seen on grass land and perennials on arable land. (Cert.)

42. What do you understand by a plant association ? Describe the general features of any *one* of the plant associations found in the following situations : (*a*) a moor, (*b*) a wood, (*c*) a marsh, (*d*) a sand dune. (J.M.B. Matric.)

43. Enumerate *five* plants you have found growing in a hay-field. In each case, (*a*) make an outline drawing of a leaf, (*b*) mention the kind of inflorescence possessed by the plant, and (*c*) state whether the plant is an annual, a biennial, or a perennial. (L.M.)

44. Mention any *five* weeds which commonly occur in cultivated soil. Explain, with the aid of diagrams, why man finds it so difficult to exterminate these plants. (L.M.)

45. Write very brief notes on the habitats of any five of the following plants :—Scotch fir (*Pinus*), ash, ling (*Calluna*), ivy, alder, wild clematis (traveller's joy), water lily, gorse, meadow-sweet, chickweed.

In the cases you select, (*a*) state whether the leaves are shed in autumn or remain on the plant during winter, and (*b*) mention the special safeguards (if any) against excessive transpiration. (L.M.)

46. Write an account of either :

(*a*) some rosette-forming plants,

(*b*) the vegetation of a strip of waste land by the side of a road.

In either account explain in what way any of the plants you mention are specially fitted for the place in which they grow. (Prel. Cert.)

47. What are the common weeds found on lawns ? Write brief notes explaining to what extent each is affected by the periodic mowing of the grass. (Cert.)

48. Describe the situations in which you would expect to find (*a*) bilberry, (*b*) cotton grass, (*c*) ribwort plantain, (*d*) bracken, (*e*) snowdrop respectively growing.

49. Describe carefully four plants you have found occurring abundantly on any waste piece of ground. For the examples you select point out the characters which are of most use in colonising waste land. (J.M.B. Matric.)

50. State under what conditions you have found any *four* of the following plants growing and how they are adapted to these conditions :—Marram grass (*Psamma*), gorse, heather, chick-weed, water-lily, wild hyacinth. (C.P. Jun.)

51. Selecting not more than three of the undermentioned plants, describe for each the usual habitat and mention any peculiarities possessed by the plant which fit it for that particular situation :—furze, ivy, wood anemone, heather, traveller's joy (clematis), water buttercup. (O.S.)

52. Describe the habitat of *five* of the following plants, and in each case give a list of plants likely to be found growing in the same habitat :—Marram grass, bracken, water-crowfoot, rock-rose, honeysuckle, poppy. (L.M.)

53. In what main respects do the stems and leaves of plants show differences which seem to correspond with the nature of their habitats? Illustrate your answer by reference to not more than *six* examples. (N.F.U.)

54. Give an account of the various influences which affect the nature of the plant life in any district with which you are familiar.

PART II.

REPRODUCTION.

CHAPTER XVI.

FLOWERS: POSITION AND STRUCTURE.

38. THE POSITIONS OF FLOWERS.

PRACTICAL.

1. Inflorescences.—Collect specimens of various common flowering plants, each bearing flowers of different stages, from unopened buds to ripe fruits, and make *diagrams*, in the manner of Figs. 196 and 198, of the flower-clusters or inflorescences. The diagrams should show (*a*) by numbers or arrows the *order* in which the flowers of each cluster open, (*b*) the positions at which the stalks of individual flowers are attached to the main stalk of the cluster, and (*c*) the positions of leaves associated with the flowers.

Group the branched and stalked inflorescences in two sets according as the order of opening is (*a*) from the bottom (or outside) of the cluster, or (*b*) in the reverse direction. In which of these groups does the growth of the axis of the inflorescence cease earlier? For which are the terms *definite* and *indefinite* respectively more suitable?

2. The massing of small flowers.—Study the means by which the small flowers of candytuft, hedge mustard, hogweed, yarrow, phlox, etc., are arranged to form flat, dome-shaped, or globular groups. How does the arrangement affect their conspicuousness? In which of these plants does the arrangement change as the flowers turn into fruits? In what way is the change for the benefit of the seeds? Examine closely the so-called "flowers" of clovers, sunflower, daisy, coltsfoot, knapweed, dandelion and scabious,

and decide whether they are really flowers or inflorescences. Make diagrams of them as seen in longitudinal section, indicating each flower by a small circle.

Look for inflorescences of sessile (stalkless) flowers (*a*) on an elongated, (*b*) on a flattened axis. Which of the stalked inflorescences do they respectively resemble most?

Reproduction.—In the foregoing chapters we have been concerned with the principal activities by which the higher plants feed and grow. These are called vegetative activities, and the organs—leaves, root and stem—performing them are therefore called vegetative organs. In Chapter XII. we studied various cases of vegetative propagation, in which plants increase in numbers by the separation and subsequent independent growth of buds or of pieces of stem, root, or leaves. Increase in numbers in this way is sometimes called vegetative reproduction, but the term reproduction is best reserved for processes by which actual offspring, that is, distinct individuals of a *new generation*, are formed (p. 211). In the higher plants this important work of reproduction is done by the flowers, which make seeds. We have found that a seed contains a resting embryo or young plant, together with a store of food.

Advantages of seed production.—The production of seeds gives the higher plants certain distinct advantages; for a seed is, in the first place, specially adapted for easy dispersion; secondly, it is often able without injury to wait for comparatively long periods, if necessary, until the conditions are suitable for its germination; and thirdly, the young plant inside the seed is the offspring of *two* parent cells of opposite sex, and it thus combines *two* sets of qualities. For the last-mentioned reason, the new plant is likely to combine in varying degree the qualities of both parents, and therefore to be able to grow in a somewhat different manner from either. In other words, sexual reproduction gives plants an opportunity to *vary*, from generation to generation (and thus to test the possibilities of success under different conditions), to an extent which would otherwise be impossible.

The work of flowers.—In studying flowers, then, we must bear constantly in mind that their work is **to make seeds,** and we must try to understand how the various details of their manner of life—grouping, colour, scent, form, structure, time of opening, etc.—help them to carry out this work. We must remember also that, as the seeds ripen, the flower itself changes into a fruit, the work of which is to bring about the efficient scattering or dispersal of the seeds; for a seed which fails to reach suitable ground is obviously a failure.

Typically—even with flowers containing both male and female organs—the two parts which actually unite to form a seed are derived from two different flowers of the same kind; the male substance (called pollen) being carried from one flower to the female portion of another flower, either by the wind or by insects.* This is called cross-pollination. Self-pollination is, however, not uncommon; in this case pollen from the same flower is used.

The positions of the flowers.—The *mechanism* of cross-pollination by wind and insects, and of self-pollination, will be dealt with more fully in Chapters XVII. and XIX., but we can understand already the great advantage, to a flower depending on insects for pollination, that it shall be both conspicuous and easily accessible, and to one pollinated by the wind that it shall be well exposed to all breezes. It is equally, if not more, necessary that the resulting seeds shall have a good chance of being scattered, and we shall see in Chapter XVIII. that this depends largely upon the positions of the fruits, which in turn depend upon the positions of the flowers. These considerations show the great importance of the positions of flowers upon the plant.

Inflorescences.—The word inflorescence is used in two senses: first, as an abstract noun, for the *manner* of arrangement of the flowers, and second, as a common noun for an actual group or cluster of flowers.

In the anemone (Fig. 243) and tulip the flower is **solitary,** and also *terminal*, that is, at the tip of the flowering axis. In scarlet pimpernel (Fig. 273) each flower arises separately in

* In some water plants the pollen is carried from flower to flower by water, and in some tropical plants by humming-birds.

the axil of an ordinary foliage leaf and the inflorescence is then said to be solitary and axillary. Any leaf, however modified, in the axil of which a flower grows, is called a *bract.**

Racemose inflorescences.—Most commonly the flowers are borne in special branched clusters. In the toadflax (Fig. 195), foxglove (Fig. 161), wild hyacinth, etc., there is a main flower stalk called the *peduncle*, on which the flowers grow alternately, each with a stalk of its own (called a *pedicel*) and arising in the axil of a small bract (*d*). It will be noticed that the flowers begin to open at the bottom of the spire-like group, and that the youngest flowers are nearest the tip of the peduncle. This kind of inflorescence is called a **raceme** (Fig. 196, *R*). Racemes are sometimes branched (Fig. 196, *P*), as in many grasses. The raceme may be regarded as the central type of a group of inflorescences, called racemose, in all of which the youngest flower is nearest the tip of the peduncle or the centre of the inflorescence.

FIG. 195.—Raceme of Toadflax. *d*, bracts. (After Strasburger.)

A **corymb** differs from a typical raceme only in having its alternate flower-stalks (pedicels) of such lengths that the flowers, instead of forming a spire, are brought to a common and more or less flattened surface. Excellent examples of the corymb are seen in candytuft and other crucifers (p. 376). Even small flowers, being massed together in this way, are rendered collectively conspicuous while being at the same time easily accessible individually to insects. It is often to be seen that as the flowers of a corymb change into fruits, the stalks lengthen, so that the collection of fruits becomes spire-like (Figs. 135 and 246); the seeds are more effectively scattered if the fruits are more widely separated, and conspicuousness is no longer an advantage.

* That a flower so frequently arises in the axil of a leaf is one of many reasons for considering it a specially modified branch.

A similar "massed" effect of flowers is obtained in the **umbel**, formed by a number of pedicels springing (like the ribs of an umbrella) from one point at the top of the peduncle (*e.g.* cherry, cowslip). In the *compound umbel* (Fig. 267), the effect is still more marked; it is produced by the similar branching of the whorled pedicels themselves.

Sessile racemose inflorescences may be supposed to have been derived from stalked inflorescences by the suppression of the pedicels. The **spike** is a racemose inflorescence of

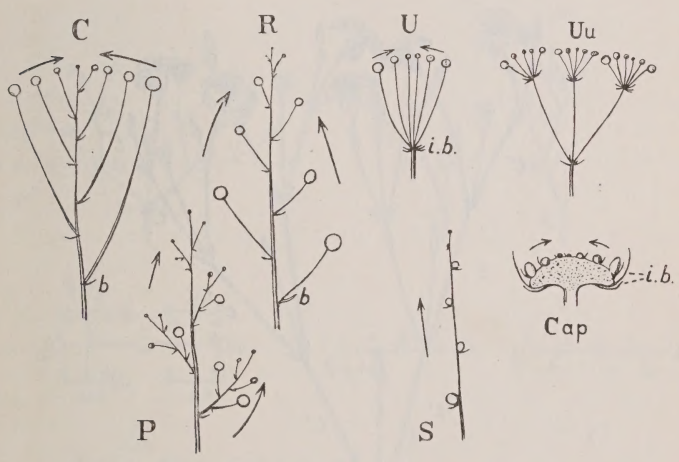


FIG. 196.—Diagrams of Racemose inflorescences. *R*, raceme; *P*, panicle (branched raceme); *C*, corymb; *S*, spike; *U*, simple umbel; *Uu*, compound umbel; *Cap*, capitulum. The arrows show the order in which the flowers open. *b*, bract; *i.b.*, involucre of bracts.

sessile *alternate* flowers. It is well shown by agrimony, the plantains (Fig. 216), early purple orchis, etc. If the flowers of a spike are either all male or all female, as in many common trees, the spike is called a *catkin* (Figs. 218 and 334). Male catkins are often elongated and dangle freely from the branch, their pollen being thus easily scattered by the wind. A fleshy spike, bearing some male and also some female flowers, is the inflorescence of the arum (cuckoo-pint); it is called a *spadix*, and the large rolled bract—so conspicuous in the closely-related "arum lily"—is called a *spathe*.

The head or **capitulum** is the characteristic inflorescence of the daisy family or Compositae (p. 402), though it is seen also in certain plants (*e.g.* honeysuckle, red clover) of other families.

It may be considered the equivalent of a sessile umbel, or of a "telescoped" spike; in it the small sessile flowers are rendered collectively conspicuous by being closely set on a disc or knob which represents the whole of the flowering region of the peduncle of other racemose inflorescences.

The essential differences between the various racemose inflorescences, and their relation to the typical raceme, are shown diagrammatically in Fig. 196.

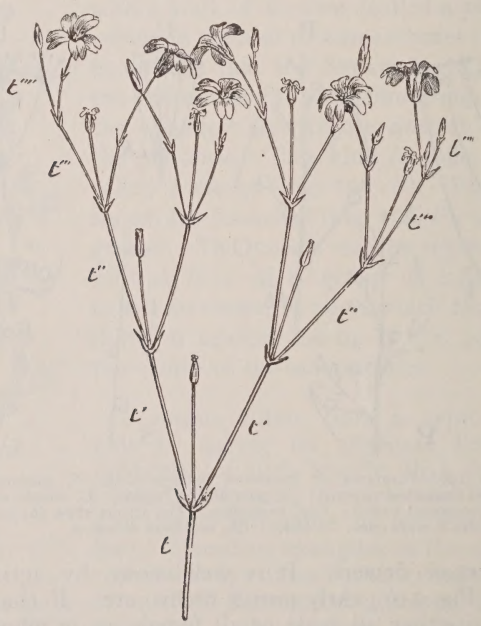


FIG. 197.—Typical biparous cyme (dichasium) of Mouse-ear Chickweed. *t-t''''*, successive axes. (After Duchartre.) Compare with Fig. 198, *A*

The method of branching of the racemose inflorescences is obviously of the monopodial type (p. 148). Such inflorescences are also frequently called **indefinite**, because the "acropetal" order of opening of the flowers (*towards* the tip of the flowering axis) often makes it doubtful how far the tip will develop.

Cymose inflorescences.—The sympodial group of inflorescences is usually described as cymose or **definite**. The main axis of a

cyme ends in a flower (Fig. 198, 1), which is the first to open; it is followed by a flower (Fig. 198, 2) arising at the tip of a branch of the main axis; this branch similarly bears one or more flowering branches. A repetition of the process results in an inflorescence in which the order of opening of the flowers is *away from* the true tip. Cymes may be (*a*) two-branched (biparous or dichasial), when the leaves (bracts) are opposite, as in chickweeds, stitchwort, campion, gypsophylla; or (*b*) one-sided (uniparous or

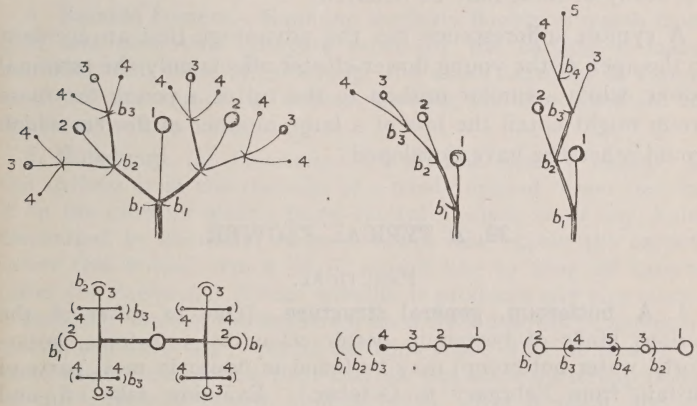


FIG. 198.—Diagrams of Cymose inflorescences, as seen from the side and in plan. *A*, two-branched or biparous cyme (dichasium), with daughter axes in opposite pairs. *B* and *C*, uniparous cyme (monochasium); one daughter axis of each pair is suppressed. (In *B* the right branch, in *C* the left and right branch alternately, is missing.) b_{1-3}, bracts in the axils of which axes 2-4 arise.

monochasial), when one branch of a pair fails to develop and the daughter axes therefore arise singly (*e.g.* buttercups, forget-me-not). In a cyme, the extent to which the tip of the inflorescence will develop is settled early; hence the term definite.

The essential difference between a racemose (indefinite) and a cymose (definite) inflorescence lies in the order of development of the flowers. In other respects the two often show a superficial resemblance; thus a cyme may have its flowers brought to a common level by different lengths of alternate flower stalks (to form a " cymose corymb " in the wayfaring tree), by whorled flower stalks of equal length (to form a " cymose umbel " in the

onion), or by being sessile and closely set on a knob-like axis (to form a " cymose capitulum " in the teasel and scabious). The cymose nature of the inflorescence is, however, revealed in all these cases by the fact that the *oldest* flower is at the tip of the main axis, *i.e.*, usually, in the middle of the group. It is interesting to find families so different in race adopting the same means of securing economical conspicuousness which we noticed in the " racemose " types. There are even " mixed " inflorescences, which are partly racemose and partly cymose, but the study of these may be deferred.

A cymose inflorescence has the advantage that an accident to the apex of the young flower-cluster affects only the terminal flower, while a similar mishap to the tip of a young racemose group might entail the loss of a large number of flowers which would otherwise have developed.

39. A TYPICAL FLOWER.

PRACTICAL.

1. A buttercup, general structure.—[One or other of the various kinds of buttercup (lesser celandine, crowfoots, spearworts, water-buttercup) may be found in flower in most parts of Britain from February to October.] Examine, take off, and draw the various parts of the flower in order, from the outside to the inside. (*a*) The **perianth**, consisting of (i) the *calyx* of 5 (3 in lesser celandine) green, separate *sepals*, and (ii) the *corolla* of 5 (8 in lesser celandine) golden-yellow (white in water buttercup), separate *petals*, alternate with the sepals and fixed at a higher level. (*b*) The **androecium** of numerous separate *stamens*, fixed higher than the corolla. In each stamen observe (i) the stalk (*filament*), and (ii) the terminal bilobed *anther*, bursting on the side farthest from the centre of the flower to liberate yellow *pollen* dust. (*c*) The **gynaecium**, consisting of numerous separate *carpels*, fixed higher than the androecium; the spiky tip of each carpel is called the *stigma*, the swollen lower part is the *ovary*. Open several ovaries with a needle, and try to see the contained *ovule* in each. (*d*) The conical **thalamus** or receptacle, to which *a*, *b* and *c* are attached at successively higher levels.

Look for older stages of the flower and notice that the oldest stage (fruit) consists only of the ripened carpels on the thalamus. Open several ripe carpels and see the contained *seed* in each.

2. A buttercup: longitudinal section.—With a *sharp* knife or a razor cut a flower lengthwise through the middle, splitting the stalk and cutting upwards. Draw ($\times 4$) the *cut* surface only, using a sharply pointed, hard pencil, and showing exactly where every part is attached to other parts. Shade or colour the thalamus differently from the rest of the drawing.

3. A buttercup: horizontal section.—With a wetted razor cut slices across buttercup *buds* of various ages and at various levels, and identify all the parts.

4. Related flowers.—Examine similarly flowers of marsh marigold and clematis. Compare especially the carpels of marsh marigold with those of buttercup, and make drawings of various stages of ripening of the former, showing the attachment of the numerous ovules.

5. Buttercup. (*a*) *Pollination.*—With fine scissors remove all the anthers from the stamens of a newly opened flower (leaving it on the growing plant), being careful to clear away any pollen discharged by the outer stamens before you expose the carpels. Cover this flower with a small muslin bag to keep off insects. Label the flower A. Notice whether it produces any ripe seeds.

Similarly remove the anthers from a second flower B, and cover it with a muslin bag ; but at the time when other flowers of the same stage are exposing their carpels, put some buttercup pollen on the carpels of B with a small brush, cover it again, and see whether it produces ripe seeds. Explain any differences in the behaviour of A and B.

Make similar experiments with other flowers.

(*b*) *Germination of pollen grains.*—Examine, with the low power of the microscope, pollen dust from various kinds of flowers. Put a little of each kind in a separate drop of sugar solution (1 level teaspoonful of sugar to $\frac{1}{2}$ pint of water) on small glass slips. Prevent the solution from drying up by keeping the slips in a moist chamber (*e.g.* under an inverted tumbler with pieces of wet blotting-paper, or inside a desiccator in which water takes the place of the usual sulphuric acid), and examine at intervals with the low power of the microscope. Draw a few pollen grains and pollen tubes.

6. Tulip flower.*—Examine and draw tulip flowers in the manner described in 1 to 3 above. The most important differences in structure from the buttercup are (*a*) the arrangement

* Star of Bethlehem or lily may be substituted.

of the parts of the flower in multiples of three,* viz. 3 sepals, 3 petals, 3 +3 stamens, 3 carpels ; (*b*) the fusion of the 3 carpels of the gynoecium to form one piece called the *pistil* ; in cross-section the 3 carpels (each containing 2 rows of ovules) are easily distinguished.

Make several cross-sections of tulip anthers of various ages with a sharp knife or razor, and draw each, showing the four chambers (pollen sacs) containing pollen. How is the pollen discharged ?

Examine similarly flowers of hyacinth and snowdrop. In what respects do they differ respectively from flowers of tulip, lily or star of Bethlehem in the union or relative position of their parts ?

A typical flower.—The student will find it best to begin the study of floral architecture by making himself familiar with the structure of some simple and common type of flower. The buttercup is one of the best for this purpose. In Britain we have several different kinds or species of buttercup, one or other of which may be found in flower during the greater part of the year. The lesser celandine is the first buttercup to flower, in February ; later the water-buttercups (white), the crowfoot buttercups and the spearwort buttercups are common.

The buttercup flower (Fig. 199) consists of a number of parts, separately, though closely, attached to the swollen tip of the flower stalk. This swollen end of the flower stalk is called the **thalamus** or floral receptacle. Taken in order from the outside to the inside of the flower, the attached parts are called perianth, androecium and gynaecium respectively. The perianth consists of the green and yellow leaves of the flower (to most people its distinctive feature) ; the androecium (a word meaning the "men's quarters") consists of the male organs ; the gynaecium (a word meaning the "women's quarters") consists of the female or seed-bearing organs.

The perianth.—In the buttercup the perianth comprises two sets of leaves. The outer set is called the **calyx** ; it is made up of 5 green leaves or *sepals* (Fig. 199, *s*) ; 3 in lesser celandine. Because the sepals are not joined together, the calyx is said to

* Usual in monocotyledons.

be polysepalous.* Because the sepals are fixed to the thalamus at a lower level than any other part of the flower, the calyx is said to be inferior.† The chief use of the calyx of the buttercup is to protect the internal parts of the young flower. In the bud stage, the calyx is the only part exposed.

Next inside the calyx, and fixed on the thalamus at a slightly higher level, is the **corolla**, consisting in most buttercups of 5

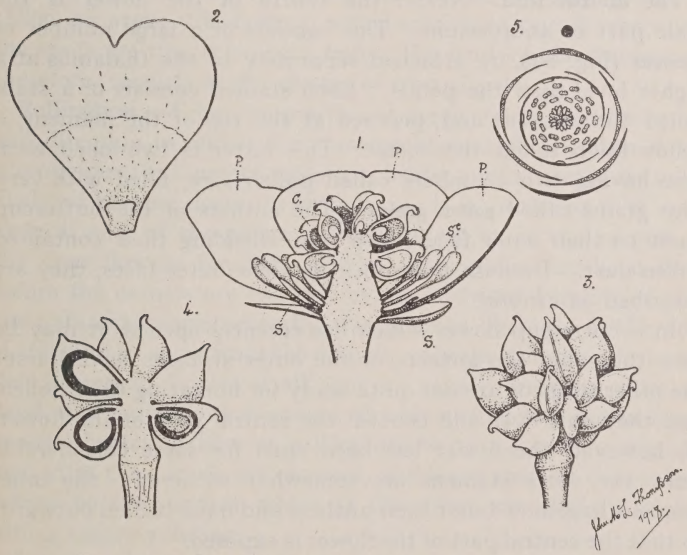


FIG. 199.—Buttercup (*Ranunculus acris*). 1. Flower in median section. 2. A single petal. 3. The gynaecium. 4. The same in section. 5. Floral diagram. *s*, sepals; *p*, petals; *st*, stamens; *c*, carpels. (After Thompson.)

golden-yellow *petals* (*p*); in the lesser celandine (Fig. 139) the petals are usually 8 in number, and in the water buttercup they are white. As the petals are not joined together, the corolla is described as polypetalous. In position the petals typically alternate with the sepals, the middle of each petal being opposite the interval between two of the sepals (Fig. 199, 5).

The bright colour of the petals makes the flower conspicuous to insects, which visit it for the sake of a sweet fluid called nectar.

* In botany, the Greek prefix *poly* means separate.

† Latin = lower.

This is contained in a little pocket, called a *nectary*, which each buttercup petal has at the base of its upper or inner surface (Fig. 199, *1* and *2*). All sorts of insects visit buttercups and crawl over the flower in search of the nectar. To obtain it, they need only to press a petal back and dip their tongues into the little pocket. Even insects with very short tongues can thus feed on buttercup nectar.

The androecium.—Nearer the centre of the flower is the male part or androecium. This consists of a large number of **stamens** (Fig. 199, *st*), attached separately to the thalamus at a higher level than the petals. Each stamen consists of a stalk called the *filament* and, perched at the top of the filament, a yellow knob called the *anther*. This latter is two-lobed, each lobe having two chambers called pollen sacs, filled with very tiny grains called **pollen grains**. The anthers of the buttercup burst on their outer faces when ripe, shedding their contained pollen dust. Because they open on their outer faces, they are described as *extrorse*.

In a buttercup flower which has recently opened, it may be seen that only the anthers of the outer stamens have burst; the other stamens are not quite ready for liberating their pollen, and they curl over and conceal the central part of the flower. If, however, the flower has been open for some considerable time, the outer stamens are somewhat withered; the inner stamens have now burst their anthers and have turned outwards so that the central part of the flower is exposed.

The gynaecium.—This central part is the female part or gynaecium. It is made up of a number of little objects (Fig. 199, *c*) with spiky tops. They are called **carpels**; each may be seen to stand separately on the top of the thalamus, at a higher level even than the stamens. Since its carpels are separate from each other, the gynaecium of a buttercup is described as *apocarpous*; from its position—higher than androecium and perianth—it is said to be superior.* The androecium and corolla, each being attached to the thalamus at a *lower* level than the gynaecium, are said to be *hypogynous*.† The spiky tip of each carpel is called the *stigma*; the rounded lower portion of the carpel is the *ovary*.

* Latin = higher. † Greek, *hypo*, below; *gune*, a woman.

The fruit.—It is likely that on other branches of the same buttercup plant, there will be found older stages of the flower, from which everything has fallen off except the carpels (Fig. 88); these are noticeably larger than the carpels of a young flower. If one be opened with a needle, it will be found to contain a **seed** nearly, or quite, ripe. If carpels of younger flowers are similarly opened, each will be seen to contain in its ovary a little grain which is evidently an early stage of a seed (Fig. 199, *4*). It is called an **ovule**. In botany, what remains of one flower when the seeds are ripe is called a **fruit**. The fruit of the buttercup, therefore, consists of the cluster of ripe carpels.

Pollination.—From the position of the nectaries, and the order and direction in which the stamens liberate their pollen dust, it is obvious that insects visiting a buttercup for nectar are very likely to become dusted with pollen. It is also clear that very little, if any, of the pollen is likely to get on to the carpels of the *same* flower; for, first, nearly all the pollen has been shed before the carpels are exposed by the outward bending of the inner stamens; and, secondly, the pollen is liberated on the side of the stamen away from the carpels. On the other hand, seeing that buttercup flowers of all ages are usually growing close at hand, it is probable that insects, already dusted with pollen from younger buttercup flowers, will happen to rub against the stigmas soon after the carpels are exposed, and leave some of this pollen behind on the stigmas, which at this stage are slightly sticky with a sugary solution.

It is easy, by such experiments as those prescribed on p. 315, to prove that flowers will not produce seeds unless pollination takes place, that is, unless pollen reaches the stigmas. In the buttercups the various circumstances just mentioned make cross-pollination much more likely than self-pollination. There is, however, a short time during which self-pollination of the flower is possible, should cross-pollination fail to take place; for when its last stamens are shedding their pollen, its carpels are already ready to receive pollen. In most kinds of buttercup, such self-pollination is effective; but the "bitter buttercup" (Fig. 199) does not produce ripe seed unless the pollen is that of a different flower. Pollen from an entirely

different *kind* of flower (*e.g.* wild rose) would have no effect whatever.

Fertilisation.—The pollen grains, having reached the stigmas, are stimulated to growth by the sugary solution which is present on the stigmas. Each grain grows out to form a very fine hollow thread (called a **pollen tube**) which bores its way through the substance of the stigma and into the cavity of the ovary. Here, in each ovary, *one* of the tubes finds its way to the ovule, and a living male cell (called a **gamete**) from the pollen tube mixes with a living female cell or gamete in the ovule. This actual union is called **fertilisation**; as a result, an embryo or young plant gradually forms in the ovule, and the ovule thereby becomes a seed.

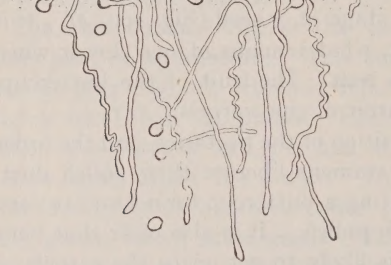


FIG. 200.—Pollen-grains germinated in the nutritive medium under a cover glass, of which the margin is shown. The tubes curve away from the margin, that is, away from the supply of oxygen. (After Molisch.)

It should be noticed that although *many* pollen grains probably reach the stigma of each buttercup carpel, only one grain can take any part in the fertilisation of the single ovule of that carpel; the rest are wasted.

In the marsh marigold, a near relative of the buttercups, the carpels are fewer, but each carpel contains several ovules (arranged in two vertical rows like peas in a pod, Fig. 206), all of which are likely to be fertilised—each by a separate pollen tube—as a result of the pollination of its particular stigma.

The chief facts of the structure of a buttercup flower may be summarised as follows:

Perianth: *Calyx* inferior, polysepalous, sepals 3 or 5.
Corolla hypogynous, polypetalous, petals 5 to 8.

Androecium: Hypogynous; stamens numerous, free; anthers extrorse.

Gynaecium: Superior, apocarpous, carpels numerous, with one ovule in each.

A still shorter way of recording the most essential facts is by using a **floral formula** in which K stands for calyx, C for corolla, A for androecium, and G for gynaecium. The floral formula of the lesser celandine, for example, is

$$K_3C_8A_\infty G_{\underline{\infty}}.$$

The sign ∞ is used for any number greater than 10, and the line drawn *under* the number of carpels indicates that the gynaecium is superior.

The tulip and hyacinth.—In certain respects flowers of the lily family (*e.g.* tulip, lily, star of Bethlehem, hyacinth) are even better material than a buttercup for a first study of floral structure. The parts are fewer in number and very noticeably in sets of three. There are six **perianth** leaves, of which the outer three may be sepals and the alternating inner three petals, though the difference between them is very slight. In such cases, where the leaves of the perianth are very similar, however, it is best for the beginner not to call them sepals and petals, but simply perianth leaves. If the perianth leaves are separate, as in the tulip, the perianth is said to be *polyphyllous*. In the hyacinth the perianth leaves are joined together (*gamophyllous*). In the lily family, as in the buttercup family, the perianth is always *hypogynous* in position.

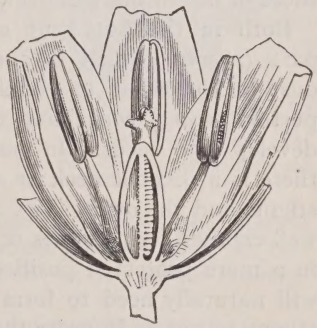


FIG. 201.—Vertical section of a flower of Wild Tulip. The perianth leaves are shown cut short. (After Oliver.)

There are only six **stamens**, in two whorls of three each; they are *hypogynous* in position in the tulip also. The stamens of the hyacinth, however, are attached to the inner face of the perianth tube (Fig. 204), and are therefore said to be *epiphyllous* * in position. The anthers are introrse, *i.e.* they open on their inner faces.

It is in the **gynaecium** that the flower of the lily family differs most obviously from that of the buttercup in build, though its position is "superior" in both; for in the lily family the

* Greek, *epi*, upon.

carpels, instead of being separate, are welded together to form a central pillar called the **pistil.** The gynaecium is therefore said to be *syncarpous*.* It is easy to see, even without cutting it across, that the tulip pistil is made up of three carpels, for the outlines of the three stigmas are clearly marked. A cross-section of the ovary shows the three carpels still more clearly, with their inner borders united to form a central column or axis, and each carpel containing two rows of ovules fixed on the axis (Figs. 203 and 204). The whole pistil of the lily family may be supposed to be equivalent to three carpels like those of marsh marigold (Fig. 206) fused together.

Both in the buttercup carpel and in the tulip pistil, the part (*stigma*) which is specially adapted to receive pollen dust and cause it to germinate is quite close to the hollow portion (*ovary*) containing the ovules, which after fertilisation develop into seeds. In most flowers, however (*e.g.* hyacinth), there is a distinct neck or stalk (called the *style*) between the stigma and the ovary (Fig. 204). This allows the stigma to be well exposed for purposes of pollination, while the ovary can be in a more protected position. In such cases the pollen grains will naturally need to form longer pollen tubes to reach from stigma to ovary, in order that the ovules may be fertilised.

The floral formula of a tulip is

$$P_{3+3}A_{3+3}\underline{G_{(3)}}$$

P_{3+3}(for perianth) is used instead of K_3C_3 because the two whorls of perianth leaves (calyx and corolla) are similar in appearance. We write A_{3+3} instead of A_6 to show that the six stamens are in two whorls of three each. The number of the carpels is enclosed in a bracket to indicate that the carpels cohere to form a syncarpous gynaecium.

The floral formula of a hyacinth is

$$\overbrace{P_{(3+3)}A_{3+3}}\underline{G_{(3)}}$$

The manner of indicating the cohesion † of the perianth leaves (the gamophyllous condition) and the adhesion ‡ of the androecium to the perianth (epiphyllous) should be noticed.

* Greek, *syn*, together.

† Cohesion is the fusion of like parts of a flower.

‡ Adhesion is the fusion of unlike parts of a flower.

Diagrams of floral structure.—The structure of a flower is best expressed by diagrams. What is called a **floral diagram** is a sort of ground plan of the flower, drawn to show in a simple manner the symmetrical arrangement of sepals, petals, stamens and carpels, which can be seen in good cross-sections of flower buds. Fig. 202 is a magnified photograph of an actual cross-section of a tulip bud, while Fig. 203 is the corresponding floral diagram. The latter shows even better than the former that the flower has its parts in multiples of three, viz., an outer whorl of three perianth leaves (sepals), an inner whorl of three perianth leaves (petals), an outer whorl of three stamens, an inner whorl of three stamens, and a central pistil of three carpels—alternating in such a way that the middle line of any member of one whorl lies opposite the interval between two members of the next whorl. The parts of the five whorls thus occur regularly on six radii; such a flower is therefore radially symmetrical.

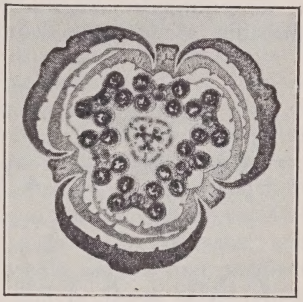


Photo. Flatters & Garnett, Ltd.

FIG. 202.—Cross-section of flower-bud of Tulip. (× 4.)

The diagram, as so far described, applies equally to the flower of a tulip, a lily and a star of Bethlehem. Now a tulip flower, being solitary and terminal, cannot be said to have a back or a front. On the other hand, where a number of flowers arise on the same stalk, it is convenient to call the side nearest the stalk the back or posterior, and that farthest from the stalk the front or anterior, side of the flower. In floral diagrams the stalk or axis of the inflorescence is represented by a dot or small circle.

FIG. 203.—Diagram of a typical monocotyledonous flower. (After Strasburger.)

The floral diagram of the hyacinth (Fig. 204) should be carefully compared with Fig. 203, and the manner of showing the cohesion of the perianth leaves and the adhesion of the stamens to the perianth should be noticed. Such diagrams should always show whether the perianth leaf nearest the axis is an inner or an outer one, and whether the partitions between the carpels are opposite outer or inner perianth leaves.

Longitudinal sections.—A "floral diagram" of the kind just described is a very useful summary of structure, but it is incomplete in that it represents the parts as if they were all on the same level; it gives no information respecting their relative heights. For this reason it should always be supplemented by a diagrammatic *longitudinal* section of the flower, made, if possible, along some definite plane marked on the horizontal diagram. Of the two sketches the longitudinal section is the more helpful to the student.

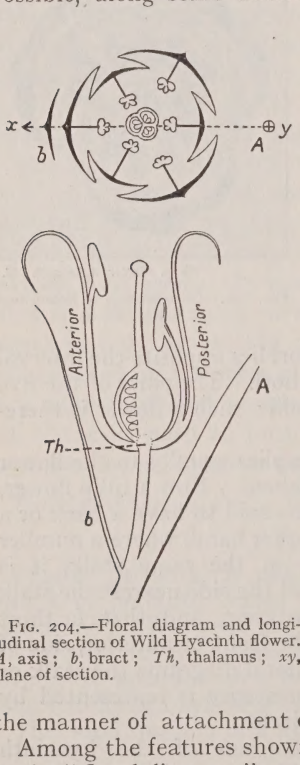


FIG. 204.—Floral diagram and longitudinal section of Wild Hyacinth flower. *A*, axis; *b*, bract; *Th*, thalamus; *xy*, plane of section.

The method of drawing such a section will be clear from Fig. 204. In this example a cut from back to front through the median plane *yx* of the flower plainly passes in turn through the axis *A*, one inner perianth leaf, the posterior or "back" stamen, one partition of the ovary, the middle of one compartment of the ovary, the anterior or "front" stamen, one outer perianth leaf, and the bract *b*. All these parts, but *only these parts*, should be shown in a student's drawing; there should be no attempt to put in a background of other perianth leaves and stamens, for the sake of pictorial effect, as is done in Fig. 201; for the main object of the section is to show clearly how and where the various parts of the flower are joined together, and it is impossible in such a drawing to show the manner of attachment of parts which are not cut through.

Among the features shown in the longitudinal section, but not in the "floral diagram," are the shape of the pistil and the height of the stigma; the relative heights of the anthers, and of the places of attachment of the two whorls of epiphyllous stamens; and the fact that the perianth is attached to the thalamus, *Th*, at a lower level than the ovary. On the other hand, the floral diagram shows many facts which the longitudinal section necessarily omits. The two together, however, give an almost complete representation of the gross structure of the flower.

40. VARIATIONS IN FLORAL ARCHITECTURE.

PRACTICAL.

1. Plasticene flower models. (*a*) *The hypogynous* * *type*.—Make a model flower, using plasticene for the stalk and thalamus, a hat pin (cut short) for pistil (with the pin-head for stigma, 2 inches of bare pin for style, and pushed through an egg-shaped piece of cork for ovary); 5 matches for stamens; 5 white or coloured cards (shaped) for petals; and 5 smaller cards, of the same colour as the thalamus, for sepals. Stick the sharpened ends of these parts symmetrically into the *knob-shaped thalamus* at appropriate heights (*i.e.* sepals below petals, petals below stamens, and stamens below ovary), and make sepals, petals and stamens alternate with each other. Why is such a flower called hypogynous?

(*b*) *The perigynous* † *type*.—Take out the pistil, and hollow the plasticene thalamus so that it is cup-shaped, with the stamens and petals now on the edge of the cup, and the calyx continuing the curve of the cup. Being of the same colour as the calyx, the thalamus now *looks like* a cup-shaped calyx with 5 points. Replace the pistil, with the ovary standing on the bottom of the cup. Why are the stamens and petals of such a flower said to be perigynous?

(*c*) *The epigynous*‡ *type*.—Turn in the cup-shaped thalamus until it completely surrounds the ovary, and notice that the sepals, petals and stamens are thereby brought to a superior or epigynous position, while the ovary becomes inferior.

2. Flower structure.—Gather, identify || and examine as many kinds of wild flowers as you can find. Whilst they are still fresh, study the symmetry, gynaecium, androecium and perianth (calyx + corolla).

(*a*) *Symmetry*.—Is it radial or bilateral (two-sided)?

(*b*) *Gynaecium*.—Make a *longitudinal section* of the flower (from back to front, if these regions are distinguishable (p. 323), so as to divide it into right and left halves), and note carefully the position of the ovary or ovaries (identified by the contained ovules). Is the gynaecium superior or inferior in position, apocarpous or

* Greek, *hypo*, below.
† Greek, *peri*, around.
‡ *epi*, upon.
|| With the help of a Flora, p. 421.

syncarpous ? Make a cross-section of the ovary. How many cavities does it contain ? Sketch the cross-section, showing how the ovules are attached. Is the style long or short ? What is the form of the stigma ? If the stigma is divided, what is the number of its divisions ?

(*c*) *Androecium*.—State the position (hypogynous, perigynous or epigynous) and number of the stamens (if more than 10, said to be indefinite). Are the stamens free from each other, or joined together by (*a*) their anthers, (*b*) their filaments ? Which part of the anther is attached to the filament ? On which side of the anther is the pollen liberated ?

(*d*) *Perianth*.—Present or absent ? If present, can you distinguish between calyx and corolla ? If not, do not assume that the leaves are petals ; call them perianth leaves, and describe them as polyphyllous or gamophyllous.

If calyx and corolla are distinct, describe the calyx as polysepalous or gamosepalous, and the corolla as polypetalous or gamopetalous. Is the calyx inferior or superior ? Is the corolla hypogynous, perigynous or epigynous ? Is the perianth regular or irregular in shape ?

3. Insect visitors.—Make a note of any insects you see on the various flowers, and try to find out if they bring about cross pollination.

The study of floral architecture.—Having become familiar with the general structure of a typical flower, the student should pass on to the examination of the commoner variations in the relations of the parts. As a useful introduction to this part of the subject he should identify, by means of a Flora,* as many as possible of the wild flowers of his district, and carefully make out their chief structural characters, paying special attention to the points mentioned above. In such study the fact should never be lost sight of that the consummation of the flower's work is the production of healthy seeds, and that every peculiarity of its structure may have some significance towards this end. The centre of interest of the flower, for the botanist, is therefore the ovary with its contained ovules—each of which can become a seed only if fertilised by a pollen tube. The rest

* See footnote, p. 421.

of the flower he looks upon as machinery for bringing about effective pollination (probably cross-pollination) of the stigma —the necessary preliminary to fertilisation.

Relative positions of the parts of a flower.—In the simpler common flowers, the end of the stalk—the thalamus or "floral receptacle"—is more or less conical or knob-shaped, with the gynaecium at its apex, the stamens standing on the sides of the cone immediately below the gynaecium, the petals at a still lower level, and the sepals lower still. In technical terms the

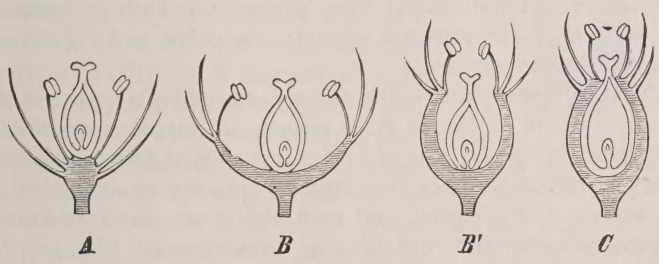


FIG. 205.—Diagram of (*A*) hypogynous, (*B*, *B'*) perigynous, and (*C*) epigynous flowers. The thalamus (Royal receptacle) is shaded. (After Strasburger.)

gynaecium of such a flower is said to be superior, the androecium (stamens) hypogynous, the corolla (petals) hypogynous, and the calyx (sepals) inferior (Fig. 205, *A*).

The chief departures from this simple condition are due to **differences in the shape of the thalamus,** which, though thus typically conical or knob-shaped, has, in different families, become flattened, saucer-like, cup-shaped, urn-shaped or even tubular, by various degrees of upgrowth of its sides. Though in all cases the gynaecium remains at the middle (the morphological apex) of the thalamus, it will be readily understood that the other regions of the flower may have been raised in this manner from the primitive hypogynous position to various heights, and by upward growth of the thalamus round the ovary the latter may be, as an extreme position, "inferior"; the stamens and corolla are then said to be epigynous and the calyx superior. In the intermediate condition, when the thalamus is flattened or hollow, without actually adhering to the sides of the ovary, the stamens and corolla are described as perigynous, and the thalamus

appears (and was formerly considered) to be the lower part of the calyx. These three conditions are well shown in Fig. 205. It is clear that with very marked perigyny and in epigyny the ovary and its contents are better protected than in hypogynous flowers. When the thalamus is specially elongated (as often in the buttercup and water-lily families) the carpels, stamens and perianth leaves tend to be arranged spirally on it. In other cases they are usually in whorls.

Let us consider the various parts of the flower in order of their physiological importance. The gynaecium and androecium are, of course, the *essential* organs; the calyx and corolla are merely *accessory* organs.

Types of gynaecium.—The gynaecium, or female part of the flower, consists of one or more **carpels.** A carpel is essentially a leaf, bearing *ovules.* In the primitive class of flowering plants which includes the pines, firs, larches, etc., the ovules occur on the surface of the carpel, and such plants are therefore known as gymnosperms: the word meaning "naked seeds" (Fig. 347, *B*). In all dicotyledons and monocotyledons, however, the carpels are folded, or joined edge to edge, to form a closed bag or box, the ovules being thereby shut in and protected.

The monocarpellary gynaecium.—The leafy nature of the single carpel (pod) of a pea or bean is very evident. Such a pod can be split open easily by pressure, giving way readily along a line which represents the joined margins of the leaf; both margins bear seeds. The part of a carpel on which ovules are borne is swollen, and called the *placenta.* The placenta is usually the margin of the carpel, as in the pea. Opposite the fused margins is the midrib, forming, as it were, the hinge of the folded leaf; when the pod is fully ripe this also splits open (Fig. 238). The hollow portion of the carpel containing the ovules (later, seeds) is called the *ovary*; above it is the solid "neck" or style, and at the end of the style is the rounded stigma. The pea flower (Fig. 259) literally carries "all its eggs in one basket."

The gynaecium of the pea is described as *monocarpellary* because it consists of *one* carpel only; the ovary is *unilocular* because it contains only one cavity (loculus); the placentation

(arrangement of the ovules) is *marginal*, and also *parietal*, because the ovules are on the wall (Latin, *paries*) of the ovary.

The apocarpous gynaecium.—The gynaecium of the marsh marigold consists of a number of carpels each very similar to the single carpel of the pea, standing separately on the thalamus. A gynaecium consisting of separate carpels is said to be **apocarpous.** The numerous carpels of the buttercup (Fig. 199) are also separate, but are shorter, and each contains one ovule only, standing on the base of the ovary. It is clear that all of, say, ten ovules are more likely to be fertilised if they are all in the same carpel, as in marsh marigold or pea, than if they are contained in ten separate carpels as in buttercup; for the pollination of one stigma would suffice for all of them, since many more pollen grains than the ten necessary are likely to be left together by an insect touching the stigma. In this respect, then, the gynaecium of the marsh marigold seems more efficient than that of the buttercup.

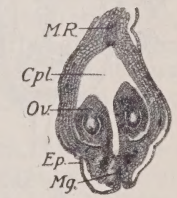


FIG. 206.—Photomicrograph of a cross-section through one carpel of Marsh Marigold. *Cpl*, cavity of carpel; *Ov*, ovule; *M.R.*, midrib, and *Mg*, fused margins, of carpel; *Ep*, epidermis (partly torn off during manipulation). (× 17.) (T. D. Tuton Hall.)

The syncarpous gynaecium.—On the same principle we may suppose a flower to have an even greater advantage if its carpels are completely joined together, for in that case all the ovules of *all* the carpels may be fertilised as the result of a single act of pollination. A gynaecium consisting of united carpels is said to be **syncarpous.**

Monocarpellary and syncarpous gynaecia are often called *pistils*.

The carpels of a syncarpous gynaecium may be so completely united as to leave no outward sign of the number of carpels present; more commonly the stigmas at least remain separate, in which case the number of carpels can be clearly made out. Thus the pistil is plainly *bicarpellary* in the dead-nettle and dandelion families, which have *two* free stigmas (Figs. 276 and 291); *tricarpellary* in stitchwort (Fig. 207), harebell and crocus (Fig. 305), which have *three*. It has four stigmas, and therefore *four* carpels, in willow herbs; and five of each in the geraniums.

Interesting evidence of the fusion of the carpels is usually to be seen in a transverse section of the ovary. In the violet, for example, it is plain (Fig. 209) that three carpels have joined together edge to edge to form a single-chambered ovary with

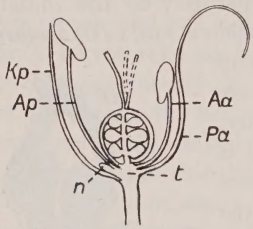


FIG. 207.

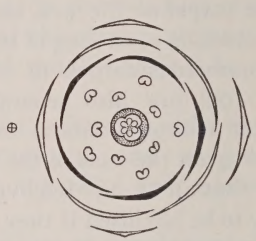


FIG. 208.

FIGS. 207 AND 208.—Greater Stitchwort. Longitudinal section of flower and floral diagram, showing superior, syncarpous, tricarpellary, unilocular gynaecium, with free central placentation. *Kp*, posterior sepal; *Ap*, posterior stamen; *Aa*, anterior stamen; *Pa*, anterior petal; *n*, nectary; *t*, thalamus.

the six carpel-margins (placentas) on its wall. The gynaecium is therefore tricarpellary and syncarpous, the ovary is unilocular, and the placentation is marginal and parietal.

It is interesting to compare the pistil of the tulip, hyacinth, daffodil, etc. (Fig. 210), with that of the violet. In these, six

FIG. 209.—Floral diagram of Violet, showing the unilocular ovary, with marginal and parietal placentation. The midribs of the three carpels are shown by small arrows. (Strasburger.)

FIG. 210.—Floral diagram of typical monocotyledon, showing trilocular ovary, with marginal and axile placentation. (After Strasburger.)

margins of the three carpels have plainly turned inward and come together in the centre of the ovary to form an axis or pillar carrying the six rows of ovules, the ovary being thus divided into three chambers. While the pistil is like that of the violet

in being tricarpellary and syncarpous, therefore, the ovary differs in being *tri*locular, and the placentation is marginal and *axile.*

The *two* carpels of the wallflower pistil are united, edge to edge, in much the same manner as the three of the violet, so that the ovary is originally unilocular. During development, however, its cavity becomes divided into two by the growth of a partition (called a " false septum " because it is not formed by the folding inward of the carpels). The placentation remains marginal and parietal (Fig. 251). Similarly, the originally bilocular ovary of the dead-nettle and forget-me-not families becomes four-chambered by the growth of a false septum across each original loculus (Fig. 278).

Placentation is said to be *free-central* when the ovary is unilocular, and the ovules are attached to a central pillar, as in the stitchwort and primrose families. (Figs. 207, 208, 272, 274.)

A *single* ovule in a carpel usually either stands on the base of the ovary (*basal* placentation, *e.g.* buttercups (Fig. 199) and dandelion, dock (Fig. 224) and grass families), or hangs from the top of the carpel (Umbelliferae (Fig. 268)).

In rare cases the whole inner face of the carpel may bear ovules (superficial placentation).

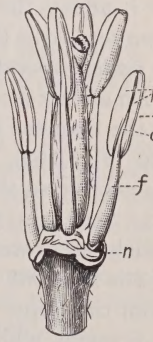


FIG. 211.—Pistil and stamens of Wallflower, the sepals and petals having been removed. *f*, filament; *c*, connective; *a*, anther; *p.l*, pollen lobes respectively of a stamen; *n*, nectary. (After Oliver.)

Types of androecium.—The male part, or androecium of the flower consists of the **stamens.** These are always further from the centre than the gynaecium, being fixed below, around, or above it, according to the shape of the thalamus (p. 327). In a large number of families the stamens are epiphyllous, that is, they adhere to perianth leaves; when in such cases the perianth leaves in question are distinctly petals, the stamens are said to be *epipetalous.*

Typically (Fig. 211), the stamen consists of a stalk or **filament** (*f*), and at the top of the filament a swollen portion called the **anther** (*a*), which produces pollen. The anther is divided by a constriction into two *pollen lobes* (*p.l.*), in each of which are two chambers called pollen sacs (Fig. 212, *A*). Between the lobes is the solid *connective* (Fig. 211, *c*); along this runs a vascular

bundle which supplies food to the pollen grains developing inside the four sacs.

When the pollen is ripe, the anther becomes dry, and a strain is set up which causes the wall to tear—usually lengthwise—between the two pollen sacs of each lobe. The loosened flaps curl back, and the pollen grains are thus exposed on the surface of the anther. As will be clear from Fig. 212 the anther opens on the side opposite the connective : if the connective is on the outer side of the anther, the pollen is discharged *introrsely*, that is, on the inner side (towards the gynaecium). It is discharged *extrorsely* (towards the perianth) in anthers which have the connective on the inner face. The direction in which the pollen is liberated is a matter of some importance, for it affects the chances of cross-or self-pollination. This has been seen to be the case in the buttercup. Less common methods of pollen liberation are by means of pores and valves, etc.

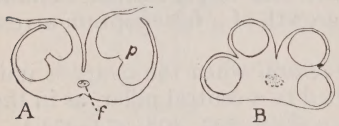


FIG. 212.—Transverse sections of anthers. In *A* the pollen sacs are ruptured; in *B* (younger stage) they are complete. *f*, vascular bundle of connective. (After Strasburger.)

An anther is said to be *basifixed* when it is attached to the top of the filament by the lower end of the connective (*e.g.* buttercup, Fig. 199), *versatile* when attached by the middle of the connective so that it can swing on the filament (*e.g.* hyacinth, Fig. 204). In the sage (Fig. 277) the two pollen lobes are widely separated by a very long connective hinged on the top of the filament. In some cases (*e.g.* grasses), the anther dangles from the upper end of the filament (Fig. 311).

Stamens which cohere by their filaments are described as *monadelphous*, *diadelphous*, etc., according to the number of groups formed (p. 384). If they cohere by their anthers, as in Compositae (p. 403), they are said to be *syngenesious*.

When the number of stamens is more than 10, it tends to vary, and is described as *indefinite*. Usually, however, the number is the same as, or a multiple of, the number of petals and sepals ; and the stamens are in one or two distinct whorls alternating in position with one another and with the petals. This is well shown in Fig. 211.

Suppression of stamens.—There is often distinct evidence that one, or three, or even a whole whorl of stamens has been lost by certain families or certain plants of a family. Thus monocotyledons have generally six stamens, and therefore the presence of three only in the iris and crocus is held to show that three have been lost or suppressed in this particular family, though the ancestors of the family must have possessed the full number (six), which is still found in nearly-related families. That the remaining stamens are those of the original outer whorl is shown by their position—alternating with the *inner* perianth leaves (Fig. 213). Again, the 5 stamens of the Primulaceae are

FIG. 213.—Floral diagram of Iridaceae, with small crosses showing the original position of the lost inner whorl of stamens. (After Strasburger.)

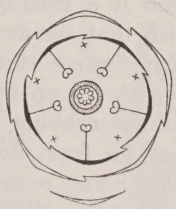


FIG. 214.—Floral diagram of Primulaceae, with small crosses showing the original position of the lost outer whorl of stamens.

opposite the 5 petals instead of alternating with them, as might have been expected. This curious state of things is explained by supposing that the ancestors of the Primulaceae had 10 stamens; an outer whorl of 5 alternating with the petals, and an inner whorl of 5 opposite the petals; but that the outer whorl has been lost or suppressed (Fig. 214). Other interesting examples of suppression are found in the descriptions of the Labiatae, Scrophulariacae, and Gramineae (pp. 395, 399 and 417).

The perianth.—While the carpels and stamens are obviously the "essential" organs of a flower—since they alone take a direct part in seed formation—the great help rendered by the "accessory" organs—the perianth leaves—must not be lost sight of.

The outer perianth leaves or *sepals* (collectively called the **calyx**) in most cases protect the rest of the flower during its early stages, and the internal organs are rarely successful if the calyx be removed prematurely. Where sufficient protection is afforded

by bracts, as in the Compositae (p. 403), or by the close crowding of neighbouring small flowers, as in Umbelliferae (p. 391), the calyx is often absent or very much reduced. Alternating with the sepals of some plants (*e.g.* strawberry, mallow) are small stipule-like outgrowths, which are collectively called an *epicalyx*.

In many cases, the sepals, like the petals and stamens, fall off after fertilisation. Often, however, the calyx persists, and may play an important part in photosynthesis for the ripening fruit, and in its protection and subsequent dispersal.

The **corolla** (consisting of the *petals*) assists the stamens and carpels chiefly by making the flower conspicuous to insects. To this end it is usually brightly coloured. Also, its *shape* is usually such that the nectar and pollen—for the sake of which insects visit flowers—are accessible only to certain kinds of insects, and that even these insects are unable to attain their object without rubbing against the anthers and stigmas, and so—as they go from flower to flower—bringing about cross-pollination. Some remarkable instances of this will be considered in Chapters XVII. and XIX.

The general *shape of the flower* depends very largely upon the extent, if any, to which the petals are joined together. This has an important bearing upon pollination, for, plainly, more kinds of insects have access to the nectar and pollen of shallow flowers than to those of flowers with deep and narrow corolla tubes, and of irregular shape.

In certain flowers (*e.g.* larkspur, violet, garden nasturtium, toad-flax, orchis, etc.), peculiar hollow outgrowths of the perianth, called *spurs*, serve as receptacles for nectar (Figs. 257 and 281). Insects cannot reach the nectar, however, without rubbing against the stamens or stigma, or both.

In the forget-me-not family, the mouth of the flower is partially blocked by scale-like outgrowths of the corolla, certain undesirable insects being thereby excluded. Similar but larger processes are found on the petals of the campion, etc., while the tube-like *corona* of the daffodil (Fig. 303) and narcissus is to be regarded as equivalent to united outgrowths of the same kind.

The shape of the perianth also often protects the nectar and pollen from being spoilt by rain.

Morphology of the flower.—There is abundant evidence that the thalamus of a flower is a modification of the end of the stem, and that the rest of the flower consists of modified leaves. The leaf-like nature of sepals and petals is obvious even at first sight; and the fact that in the white water-lily, cultivated roses, and other "double" flowers, all intermediate stages between ordinary petals and normal stamens are found, confirms other evidence that stamens also are modified leaves, the filament representing the stalk and the anther the leaf-blade. Similarly, "double" flowers are not uncommon in which the carpels are replaced by petal-like structures.

Floral symmetry.—Most flowers have their parts arranged symmetrically so as to appear, in ground plan, on equidistant radii of a circle, and with the members of one whorl alternating with those of the next. This has been seen to be the case, for example, in the hyacinth (Fig. 204). A longitudinal section, made in the plane of *any* radius, divides such a flower into similar halves. Such a flower is said to be **regular, radially symmetrical,** or **actinomorphic.**

Fig. 215.—Bilaterally symmetrical (*zygomorphic*) flower of Snapdragon. (After Figuier.)

On the other hand, the flower of a sweet pea, pansy or snapdragon (Fig. 215) is plainly two-sided, as is (say) a human head. Its "right" side is like its "left" side, but the back is not like the front. There is only one plane along which it can be divided into similar halves. Such an **irregular** flower is said to be **bilaterally symmetrical,** or **zygomorphic.**

There is a general tendency for each whorl of a flower to consist of the same number of parts. In most monocotyledons, as we have seen, the parts of the flower are in multiples of three. In dicotyledons the characteristic number is usually five, though multiples of four or two are not uncommon. The number of carpels is, however, often less, and the number of stamens often more, than the number of petals.

EXERCISES XVI.

1. Describe carefully the inflorescences of any *two* plants you know. What advantages do you suppose the inflorescence has over the single flower? (J.M.B. Jun. Cert.)

2. Make sketches to show three common ways of grouping, by which small flowers are rendered conspicuous.

3. What is an umbel? Make a careful drawing of an example and point out how the plant is benefited by the possession of an umbel. (C.J.)

4. Explain, with the aid of diagrams, the difference between racemose and cymose inflorescences. Elucidate your statements by reference to (*a*) stitchwort, (*b*) willow *or* poplar, (*c*) sunflower, (*d*) carrot *or* hedge parsley, (*e*) forget-me-not. (O.S.)

5. Mention *three* plants in which the flowers are massed together in a dense inflorescence. What is the advantage of this arrangement?

Describe, with diagrams, any differences in structure you have observed between the central and marginal flowers of the inflorescences you mention. (O.S.)

6. What do you understand by a flower? Describe the form, arrangement and function of the various parts of any flower you have examined. (J.M.B. Sch. Cert.)

7. Draw a floral diagram and a longitudinal section of the flower supplied. In what respects does this flower (*a*) resemble, (*b*) differ from the buttercup? (O.S.)

8. Dissect specimen C, and make labelled drawings to illustrate the structure and arrangement of its parts. C = Roman hyacinth. (C.J.)

9. What are the stamens of a flower? Write a short account of their structure and use, giving diagrams.

10. How would you investigate experimentally the function of pollen? (Part question, C.S.)

11. What are the parts of a flower essential to seed formation? Outline their structure and functions, and explain how the plant breeder makes use of them in hybridisation. (Cert.)

12. What is the use to a plant of the undermentioned structures: lenticels, root-hairs, stomata, stigma, leaf-veins, bud-scales? (C.P.)

13. Make a floral diagram of the specimen provided. Remove the sepals and petals and make a large drawing of the rest of the flower. Cut the ovary across and draw a section showing the places where the ovules are attached.

Label all the parts shown in your drawings, and add any further notes necessary to explain them. [Single stock.] (J.M.B. Sch. Cert.)

14. Make a list of not more than six plants in each case that you would select to illustrate striking differences in

(*a*) stem development;
(*b*) flower structure.

Indicate clearly the special point which each specimen would illustrate. (Cert.)

CHAPTER XVII.

FLOWERS AND THE MAKING OF SEEDS.

41. THE MECHANISM OF POLLINATION.

PRACTICAL.

1. Wind-pollinated flowers.—Examine the following plants in the months named, find the flowers, and make notes and drawings of (*a*) any features of the stamens favouring the dispersal of their pollen by wind, (*b*) any features of the stigmas helping them to intercept and retain wind-borne pollen : Oak (April, May), beech (April, May), birch (March, April), hazel (Feb., March), alder (March, April), sweet chestnut (April, May), poplar (March-May), pine (May, June), nettles (June-Sept.), plantain (June-Oct.), dock (June-Aug.), sorrel (May-July), grasses (May-Sept.).

If possible examine pollen grains of these plants with the microscope, and make drawings of them.

2. Insect-pollinated flowers.—(*a*) In March or April, examine the female catkins (" silver palms ") and male catkins (" golden palms ") of willows. What kinds of insects visit them ? How are the catkins made readily visible ? Are they scented ? Try to find the nectary at the base of each flower.

(*b*) Examine as many flowers as possible which have a conspicuous corolla or calyx, and try to discover the method of pollination. Can pollen from the same flower fall on the stigma ? Find out whether the flower discharges its pollen at a time when the stigma is mature ; if not, is the pollen or the stigma ready first ? Find the nectar, if any, then dip the end of a thin rod (wire or grass stem) successively into the nectar of several uninjured flowers of the same kind and notice whether the rod necessarily touches either anthers or stigma. Write down the names of flowers having (i) exposed nectar, (ii) partly concealed nectar, (iii) fully concealed nectar, (iv) nectar at the bottom of a tube.

Notice whether the flowers of each group are chiefly visited by flies, beetles, wasps, hive bees, humble bees, butterflies, or moths. Catch specimens of the insects which commonly haunt the flowers studied, and note the length of the proboscis in each case.* Has this any obvious relation to the position of the nectar? Describe any means by which the insect in question is likely to cross-pollinate the flower. Do insects visit a similar flower from which the petals have been removed? Mention any flowers you find are visited regularly by large insects (*e.g.* humble bees). Have the flowers an alighting platform for the insects? By what means do such flowers exclude small insects, which might obtain nectar without causing cross-pollination?

Bees are said to prefer blue or purple flowers, and butterflies red flowers; make observations on this question and keep notes of your results. Look in the late evenings for moths visiting flowers of honeysuckle, white campion, tobacco and evening primrose, and observe the length of their "tongues." By what means do the moths find these flowers in the dusk?

If possible, examine microscopically and draw pollen grains of various insect-pollinated flowers.

The advantages of cross-fertilisation.—Experiments with many flowering plants have shown that when ovules are fertilised by pollen from the same flower or from a different flower of the same plant (self-fertilisation), the resulting seeds are usually smaller and produce less vigorous plants than when the pollen comes from a different individual of the same kind† (cross-fertilisation). Moreover (p. 308), the offspring resulting from cross-fertilisation are more likely to vary among themselves, and so in each generation to give the race opportunities to adapt itself more perfectly to its condition of life, or to cope with new conditions.

Cross-fertilisation being evidently an advantage, it is not astonishing to find that flowers of very many plants have features which make it easy for "foreign" pollen, but difficult for their

* Kill if necessary by putting them into a "killing bottle" (*e.g.* one containing "rock ammonia").

† Pollen from an entirely different kind of plant is incapable of fertilising an ovule. "Crossing" is only possible between closely related plants.

own pollen, to reach the stigma. Some species depend on the **wind** for the transfer of pollen from flower to flower, and hang out feathery stigmas which catch air-borne pollen grains. Many other flowers obtain the services of **insects** as pollen carriers, attracting their attention, and encouraging their visits, by bright colours, fragrance, sugary nectar (the basis of honey), and often a superabundance of nutritious pollen.

Some advantages of self-fertilisation.—On the other hand, self-fertilisation has certain advantages over cross-fertilisation. It is, in general, more easily achieved, for most flowers are **hermaphrodite** (that is, they contain both stamens and carpels), and therefore the pollen which would suffice for self-fertilisation is already close at hand, while the pollen used for cross-fertilisation must be brought from some distance. Self-fertilisation is also more economical, since it does not entail the production of so much pollen, or the elaborate machinery needed to ensure cross-pollination. There is, moreover, always a risk that the means of transport of pollen from plant to plant—be it insects or wind—may not be available when it is needed. This risk is so great with short-lived plants—whose one opportunity of seed-production is very brief—that many species (p. 347) make no provision for cross-fertilisation, but are regularly self-fertilised.

Different methods of securing fertilisation.—Bearing in mind, first, that cross-fertilisation is in general more efficient than self-fertilisation; and, secondly, that even self-fertilisation has advantages over mere vegetative propagation, we have to consider, (A) means by which self-fertilisation is rendered improbable or impossible; (B) means by which cross-fertilisation is rendered probable; and (C) means by which self-fertilisation may be resorted to, should cross-fertilisation fail to occur.

(**A**) **Obstacles to self-fertilisation.**—Though pollination (the access of pollen to the stigma) is normally followed by fertilisation (the union of a male cell from a pollen tube with the female cell of an ovule) this is not always the case. In many plants (bitter buttercup, certain Leguminosae, dog-violet, etc.), pollen from the same flower has no effect; such flowers are said to be **self-sterile.** Even when there is no self-sterility, pollen from

the same flower is less vigorous than that from another flower of the same kind, and if both reach the stigma it is the "foreign" pollen which is successful in fertilising the ovules.

Structural barriers.—Flowers in which the stamens and the stigma come to maturity at the *same* time are said to be **homogamous.** In such cases there is usually some structural barrier against self-pollination. Thus the anthers may be extrorse (*e.g.* buttercup), or at a much lower level than the stigma (*e.g.* pin-eyed primroses (Fig. 272, *B*) and cowslips), or, as a further preventive, the receptive surface of the protruding stigma may be so placed or shielded that while it can be touched by insects which are entering the flower (and probably carrying "foreign" pollen), it is protected from contact with insects leaving, that is, insects dusted with pollen from the same flower (*e.g.* pansy, deadnettle, musk, iris, pp. 383, 397, 400 and 417).

FIG. 216.—Spike of *Plantago lanceolata.* The flowers are protogynous, and as the lowest open first, flowers in the later male stage are always *below* those in the early female stage and cannot shed pollen on them. (After Duchartre.)

Sexes separated in time.—A very usual obstacle to self-fertilisation is that a flower discharges its pollen at a time when its stigma is not "receptive," that is, not in a condition to cause the pollen grains to germinate and form pollen tubes. On the other hand, when the stigma is "receptive," the stamens of the same flower have either withered or not begun to shed their pollen. Such flowers, the anthers and stigmas of which mature at different times, are said to be **dichogamous.** If the anthers ripen before the stigmas (the more usual condition), the flower is "male" at first and "female" at a later stage, and it is said to be *protandrous**; if the stigma ripens first and the anthers afterwards, as in plantains (Fig. 216), the flower is female first and male later, *i.e. protogynous.** When there is

* Greek: *protos,* first; *andra,* man; *gune,* woman.

no overlapping of the periods of maturity of anthers and stigma (*e.g.* pink), self-fertilisation is obviously impossible. In most flowers, however, there is a time when anthers and stigma are both ripe (that is, when the flower is both male and female), and when, therefore, self-fertilisation is possible should cross-fertilisation fail to take place.

Unisexual flowers.—An extreme condition of dichogamy occurs in cases where either the gynaecium or the androecium, instead of merely maturing late, fails altogether to develop. The result is that the flower is unisexual. If only the androecium is present, a unisexual flower is said to be *staminate* or male; if only the gynaecium, it is *pistillate* or female. With such flowers, self-fertilisation is obviously out of the question. When unisexual flowers of both kinds are borne by the same plant, the plant is said to be **monoecious**.* Many trees (*e.g.* oak, hazel, sycamore, pine) as well as herbs (*e.g.* coltsfoot, p. 405) are monoecious. Plants of which some individuals bear only male flowers, and others only female flowers, are said to be **dioecious**† (*e.g.* willow and poplar, white campion, hop, white briony, black briony).

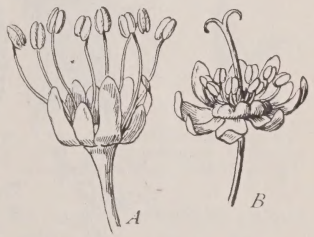


FIG. 217.—Sycamore. *A*, male flower. *B*, female flower. (Both enlarged.) Both kinds of flower occur on the same tree. (After Eichler.)

Unisexual flowers also occur along with hermaphrodite flowers in some plants. The sycamore (p. 429) is an example. The daisy, like various other Compositae (p. 405), has tubular hermaphrodite "disc-florets" in the middle of its capitulum, but conspicuous strap-shaped female florets (ray florets) around the edge.

(**B**) **Adaptations for cross-pollination.**—Such obstacles in the way of self-fertilisation would be worse than useless if they were

* *i.e.* the two kinds of flowers have a "single home" (Greek, *monos*, single; *oikos*, home).

† *i.e.* the two kinds of flowers have "separate homes" (Greek, *di*, twice; and *oikos*).

not accompanied by some means of rendering cross-fertilisation probable. Cross-fertilisation cannot occur unless pollen is carried from flower to flower either by the wind or by insects, or more rarely, by water, snails, etc.

Wind-pollination.*—In the majority of British trees, and indeed in most unisexual and many hermaphrodite flowering plants, pollination is by the wind. The flowers must produce a very

FIG. 218.—Hornbeam (monoecious and wind-pollinated). 1, branch with male catkins projecting from the buds of the preceding year, and female catkins on the growth of the current year; 2, female catkin in fruit; 3, male flower; 4, stamen; 5, bract with two female flowers; 6, female flower; 7, fruit. (1, 2, 7, $\times \frac{1}{2}$; 3-6 enlarged.) (After Strasburger.)

large amount of pollen, for, obviously, only a small proportion of wind-borne pollen is likely to reach the stigmas of flowers of the same species. Such flowers, therefore, either have many stamens or specially large anthers, or else the male flowers are much more numerous than the female flowers. Moreover, the pollen grains are dry, smooth and light, and therefore do not stick together nor fall readily to the ground. The male flowers

* The student should avoid speaking of wind-*fertilised*, or insect-*fertilised* flowers. Only pollen can fertilise a flower.

are frequently in dangling catkins (oak, hazel, hornbeam, poplar, nettle), or the anthers swing out on long filaments (as in plantains and grasses, Figs. 216 and 311), so that their pollen is easily shaken out by the wind.

The pistils of wind-pollinated flowers have often large and much-branched stigmas (Fig. 311) likely to retain any pollen grains reaching them. Wind-pollinated flowers are usually small, green, and otherwise inconspicuous ; for the wind—unlike

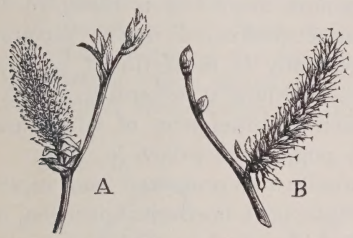


FIG. 219.—Willow. *A*, Catkin of male flowers ; *B*, Catkin of female flowers (on separate trees). (After Figuier.)

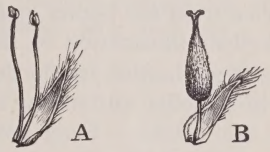


FIG. 220.—Willow (insect pollinated). *A*, male flower ; *B*, female flower (magnified). (After Figuier.)

insects—is not to be turned out of its course by bright colours. Nectar and fragrance, to which the wind is equally indifferent, are similarly absent.

Insect-pollinated flowers are visited by insects for the sake of food. This is most commonly a sugary liquid called *nectar*, formed by glands called nectaries, which may occur on the calyx, corolla, stamens, ovary or thalamus in different species. When very abundant, the nectar collects in the corolla tube, or in pouches or spurs. Its position is such that the visitor cannot obtain it without rubbing against the anthers, or the stigma, or both in turn. The petals of certain flowers have coloured lines or spots which, because they point towards the nectar, have been called "honey guides" (*e.g.* pansy, etc.).

Though the chief attraction is nectar, bees, beetles, and some flies also use *pollen* as food. Indeed, some flowers which do not secrete nectar are visited regularly for pollen, enough of which is produced to provide for the insects' needs as well as to serve for pollination. Examples of such "pollen flowers" are poppy, clematis, wood anemone, dog rose and gorse (p. 385). Various

beautiful devices by which the structure of flowers renders cross-pollination an almost inevitable result of insect visits are described in detail in Chapter XIX. See especially pp. 383, 394, 398, and 406.

Economy in pollen.—Insect-carried pollen usually differs from wind-borne pollen by having a rough or sticky surface, and hence by being more likely to adhere to the hairy bodies of insects. It is also (except in the case of "pollen flowers") produced in much smaller amount, since less is likely to be wasted. The stigma of an insect-pollinated flower becomes very sticky when the ovules are ready to be fertilised, so that pollen from the bodies of insects touching it adheres to it. An excellent illustration of the essential differences of wind- and insect-pollination is afforded by poplar and willow (p. 410).

Both pollen and nectar are usually well protected from injury by rain or dew. Some flowers take up a horizontal position, or hang mouth downwards (heather, foxglove, daffodil, hyacinth, etc.); others close, either individually or in a group, in damp weather (*e.g.* tulip, crocus, lesser celandine, daisy, etc.); some are roofed over by bracts (*e.g.* hornbeam, hazel) or have their anthers or nectaries shielded by some other part of the flower (*e.g.* monkshood, sage, iris). Finally, many pollen grains are unwettable, because covered by wax or fine spines.

Pollinating insects.—The insects most concerned with the cross-pollination of flowers are bees (especially humble bees and hive bees), butterflies and moths, flies and certain beetles.

Flies and beetles have but short tongues, and can therefore obtain nectar only if it is freely exposed. *Shallow flowers* (*e.g.* Umbelliferae, buttercups, stitchwort, cinquefoil, as well as the smaller flowers of many families) are consequently haunted by all the kinds of insects mentioned above, as well as by others. Flowers with narrow corolla tubes (campions, red clover, thistles, honeysuckle, primrose, narcissus) or with spurs (larkspur, violet, toad-flax) have *deeply placed nectar* which—since most small insects, unlikely to effect pollination, are excluded by hairs and scales, or by the shape of the flower (pp. 385 and 399)—can be reached only by insects having a long, sucking proboscis. This varies in size, being $\frac{1}{4}$ inch long in hive bees, $\frac{2}{5}$ inch in the bee-like hover-fly *Eristalis*, $\frac{3}{5}$ inch in many common butterflies

(*e.g.* cabbage white, lesser tortoiseshell) and moths, and $\frac{7}{8}$ inch in the humble bees *Anthophora* and *Bombus hortorum*. It is especially long in the hawk-moths, and in the convolvulus hawk-moth it reaches an astonishing length (more than 3 inches).

The more intelligent insects soon learn which flowers have nectar within their reach, and do not waste time upon others. Thus the nectar of red clover and various other flowers, which humble bees sip whilst unconsciously effecting cross-pollination, is inaccessible to the shorter-tongued hive bees. Similarly, hawk-moths obtain nectar from and pollinate certain flowers (*e.g.* honeysuckle) which bees perforce neglect. The correspondence between the structure of many flowers and that of the insects which usually pollinate them is remarkably close, and almost suggests the relation between lock and key. This

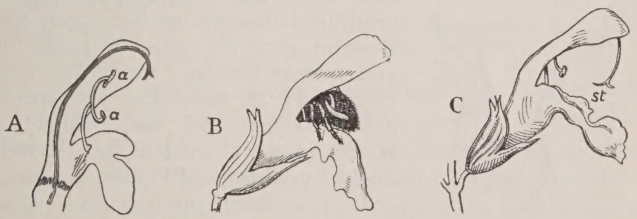


FIG. 221.—Zygomorphic flower of Sage, adapted for insect-pollination. For details, see pp. 397-8. (After Avebury.)

is especially marked in the case of irregular ("zygomorphic") flowers, which usually have one or more perianth leaves modified to provide an alighting platform for the pollinating insect (Fig. 221).

It is an interesting fact that bees have a habit of keeping to one kind of flower on one journey. The waste which would result from the deposition of "foreign" pollen on the stigma is thus avoided*; also, no doubt it is an advantage that the pollen which each bee takes home after each journey is all of one kind. On the other hand, large humble bees often save themselves trouble by biting through the flower (*e.g.* monkshood, dead-nettle, snapdragon, toad-flax, broad bean) from the outside, and obtaining the nectar without effecting pollination.

How insects are attracted.—Nectar and surplus pollen would, of course, be produced in vain if insects were unable to find the flower. There must be some means of attracting the attention of suitable insects. For this reason the flower is

* See footnote, p. 338.

either scented or conspicuous, or both. The most **fragrant** flowers often grow in dimly-lighted places (*e.g.* sweet violet, woodruff, honeysuckle) or are open at night; on the other hand, some specially conspicuous flowers are without scent.

A flower is usually rendered **conspicuous** to insects by the size and colour of one or both series of perianth leaves. Sometimes the calyx is the more brightly coloured (*e.g.* fuchsia), while the corolla is either inconspicuous or quite absent in many Ranunculaceae (*e.g.* Christmas rose, clematis, anemone, marsh marigold, etc. (p. 374)). Such a calyx (often mistaken for a corolla) is described as petaloid (petal-like). Most commonly, however, it is the corolla which is coloured and attracts attention. It is easily shown that insects do not notice a flower from which the coloured perianth leaves have been removed, while they repeatedly visit uninjured flowers on the same plant. Bees in general seem to prefer blue and purple flowers; butterflies (which chiefly fly in sunshine) are specially attracted by red and white; and moths (most of which fly abroad at dusk) by white and yellow.

FIG. 222.—Vertical section of flower-head of Corn-flower, one neuter ray-floret and one disc-floret being left. (After Oliver.)

It has been pointed out already (p. 307) that small flowers are often rendered collectively conspicuous by being massed to form heads, umbels, or corymbs; the cluster is made still more striking by the large size or irregular shape of the corollas of the outer flowers. In the corn-flower (Fig. 222) and the guelder rose, the outer flowers of the head are actually sterile (neuter), and serve only to attract insects to the group of fertile flowers which they surround. Insects crawling over the flat or domed inflorescences naturally transfer pollen from flower to flower. The male catkins ("golden palms") of willow and the spikes of meadow-plantain (which also are sometimes insect-pollinated) owe their conspicuousness to the bright colour of the stamens.

(C) **The safeguard of self-pollination.**—If for any reason they fail to be cross-pollinated, certain flowers adopt self-pollination as a last resource. The stigmas of an unfertilised flower of dandelion and other Compositae (p. 402), of willow herb, harebell, etc., at last curl back so that their receptive surfaces touch the

pollen already discharged by the flower (*D*, Fig. 223). In certain other cases the stamens themselves bend inwards and deposit pollen on the stigma (Fig. 268). The violet, wood-sorrel, and some other plants ensure self-fertilisation—should cross-pollination fail—by producing at the end of the season small *cleistogamic* flowers, that is, flowers which never open, but in which self-pollination and fertilisation take place.

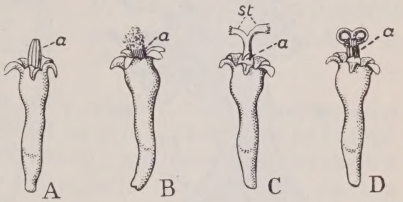


FIG. 223.—Self-pollination in Compositae (Feverfew). *a*, stamens. *st*, stigma.

Certain short-lived plants (annuals and ephemerals), although they possess all the machinery by which the leisurely perennial plants of their families sooner or later secure cross-pollination, have definitely abandoned the practice, and are regularly self-fertilised—the anthers touching and pollinating the stigmas of the same flower. The certainty and economy thus secured (such flowers are mostly small) evidently compensate for the sacrifice of the special advantages of cross-fertilisation. Examples of such regularly self-fertilised flowers are the cultivated cereals (wheat, oats, barley, etc.), sweet pea, garden pea, shepherd's purse, chickweed, groundsel, certain small geraniums, etc.

42. FERTILISATION AND ITS RESULTS.*

Fertilisation.—The hollow thread called a pollen tube, formed by the germination of a pollen grain on the stigma (which when mature is without epidermis), bores its way through the tissue of stigma and style, enters the cavity of the ovary, and finds an ovule, with which it unites.

An **ovule** ready for fertilisation is a small body, more or less egg-shaped. Its axis is sometimes in a line with the stalk (Fig. 224), but oftener bent over to lie parallel with the stalk. The ovule consists of a central mass of tissue called

* This account refers to dicotyledons and monocotyledons only. In the "lower" flowering plants (p. 459) the process is somewhat different.

the *nucellus* (Fig. 224, *nu*), surrounded by either one or two coats called *integuments* (*ii*, *ie*), which are incomplete at the end, leaving a pore called the *micropyle* (*mi*), so that here the nucellus is exposed. One of the cells of the nucellus, near or at its micropyle end, is very large, and is called the *embryo-sac* (*e*).

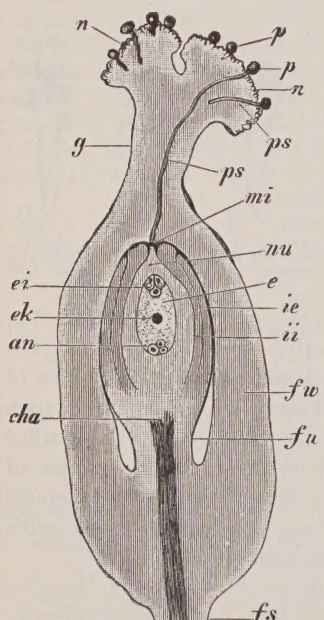


FIG. 224.—Ovary of Dock during fertilisation. *fs*, stalk-like base of ovary; *fu*, stalk of ovule; *cha*, end of vascular bundle; *nu*, nucellus; *mi*, micropyle; *ii*, inner, *ie*, outer integument; *e*, embryo-sac; *ek*, central nucleus of embryo-sac; *ei*, egg apparatus (the lowest of these three cells is the female gamete); *an*, antipodal cells; *g*, style; *n*, stigma; *p*, pollen-grains; *ps*, pollen-tubes. (× 48.) (After Strasburger.)

At this stage the embryo-sac contains seven small cells, two of which are of special importance. One, near the micropyle, is the **egg-cell** or **female gamete**; the other, near the middle of the embryo-sac, may be called the *central cell* (*ek*). They are without cell walls.

Inside the **pollen tube**, and close to its end, there are now two **male gametes**—cells also without cell walls. The pollen tube continues its growth to the micropyle, which it enters. The cellulose end of the tube breaks down and the two male gametes enter the embryo-sac. One of them fuses with the female gamete—this union constituting the act of *fertilisation*—and the combined cell thus formed divides repeatedly until it becomes an **embryo**, or young plant.

The other male cell from the pollen tube similarly unites with the "central" cell of the embryo-sac, and the combined cell thus formed divides repeatedly to form a tissue called *endosperm*. From the first, the endosperm is richly nutritious, and forms a store of food for the embryo, developing along with it in the embryo-sac. Usually the embryo-sac and its contents are the only part of the nucellus to persist, but in some cases the rest of the nucellus becomes an additional nutritive tissue called *perisperm*.

The results of fertilisation.—The consequences of the double act of fertilisation just described are far-reaching. Whilst the

fertilised egg cell (the united male and female gametes) becomes an embryo, and the fertilised "central cell" forms endosperm, the ovule as a whole gradually "ripens" until it becomes what we call a **seed**, and its integuments become the seed-coat. In some cases the surrounding food-tissue is all used up by the embryo during the ripening process, and the seed is then said to be *exalbuminous*. If, however, any endosperm (or perisperm) is left when the seed is ripe, the latter is described as *albuminous*.

If, as occasionally happens, any new structure develops on a seed after fertilisation, it is called an *aril*. Thus the ripe castor-oil seed bears a wart-like outgrowth; a willow seed develops a tuft of hairs; the seed of the spindle tree and yew have a coloured fleshy covering like an extra seed-coat; a gorse seed has a little juicy outgrowth at one end. These are all arils. That of the castor-oil seed absorbs water for germination (p. 30); the other arils mentioned help to secure the scattering of the seeds (Chap. XVIII.).

The other parts of the flower also change in varying degrees during the ripening of the seeds. The ovary wall is henceforth best called the **pericarp**: it may be a dry skin or box, or be more or less fleshy when the seeds are ripe. The thalamus also often undergoes remarkable changes (p. 355). The petals and stamens usually drop off; the calyx sometimes shrivels up, but often persists without much change; the flower-stalk often elongates and hardens, thereby assisting in various ways (pp. 310 and 364) in the dispersion of the seeds.

In any case, what is left of one flower when the seeds are ripe, together constitutes a **fruit**.

EXERCISES.

1. Write an illustrated essay on "Stamens, their function and form in relation to pollination." (Cert.)

2. Describe, with the aid of diagrams, the structure of *four* flowers provided with nectaries. What advantages do the plants derive from the production of the nectar? (O.S.)

3. What kinds of leaves, other than foliage leaves, occur in plants? Give a definite illustration of each, and explain in each instance why you regard the structure as a leaf, and state its functions. (O.S.)

4. What is meant by "zygomorphic"? Explain the possible advantages to the plant of zygomorphy, illustrating your answer by descriptions of *two* zygomorphic flowers. (C.S.)

5. Explain exactly how you would try to find out—

(*a*) if the flowers of a chosen plant can fertilise themselves;

(*b*) if the flowers of a chosen plant are naturally cross-fertilised. (Prel. Cert.)

6. What do you understand by "pollination"? Carefully describe, with diagrams, *one* example of a method by which pollination may be effected. (C.J.)

7. When is a flower said to be dichogamous? Mention one British example of each of the two types of dichogamous flowers, and explain the method of pollination in each case.

8. Describe carefully the means by which pollination is effected in three wild plants with which you are familiar. Choose the three so as to include methods which are as unlike as possible. (C.J.)

9. What exactly do you mean by *pollination*? In what various ways may it be effected? Describe fully the pollination of any flower you know. (J.M.B. Jun. Cert.)

10. What are the advantages and disadvantages of wind-pollination?

11. What are the chief characteristics of wind-pollinated flowers in general? Fully describe, with the aid of drawings, one example.

12. For what purposes do insects visit flowers? Describe the structure of two flowers adapted for the visits of insects. (O.J.)

13. Name one flower which is pollinated by short-tongued insects and another which is pollinated by long-tongued insects. Describe, with the aid of sketches, the mechanism of pollination in each case.

In what ways do wind-pollinated flowers differ in structure from insect-pollinated flowers? (L.M.)

14. How can you generally recognise flowers adapted for pollination by insects? Illustrate your answer by a description of *two* examples of flowers pollinated by long-tongued, and *two* by short-tongued insects. (O.S.)

15. Describe, with the help of drawings, the changes which take place in the external appearance of any named flower after it has been fertilised.

16. Describe the structure of a typical hermaphrodite flower, and state the functions of its various parts. What changes (not microscopic) take place in each of these parts after fertilisation? (L.M.)

CHAPTER XVIII.

FRUITS AND THE DISPERSAL OF SEEDS.

43. THE MORPHOLOGY OF FRUITS.

PRACTICAL.

1. Achenes.—Examine buttercup fruits. Make a longitudinal section through a ripe fruit (by splitting the upper end of the stalk and cutting upwards). Draw, showing the group of separate ripe carpels (achenes) on the thalamus. Dissect several achenes with needles. How many seeds does each contain? Examine in the same way various stages in the change from flower to fruit, of anemone, herb bennett and strawberry. How do they resemble and differ from each other? Cut open a rose hip and draw the achenes in position on the *inside* of the fleshy red thalamus.

Examine a sunflower fruit (so-called "seed") and a wheat grain, and give reasons for considering them achenes rather than seeds. Examine a hazel nut or an acorn. Crack open the woody pericarp (shell) and see the seed inside.

2. Schizocarps.—Draw and compare half ripe with fully ripe fruits of sycamore, radish, hogweed, dead-nettle and mallow, and open the parts into which these fruits split when ripe. In what respects are these parts like buttercup achenes?

3. Drupes.—Crack a cherry or plum "stone" to see the seed inside. Everything outside the seed is the pericarp; describe the various regions of the pericarp of a cherry or plum fruit.

Make and draw longitudinal sections showing various stages in the development of the blackberry or raspberry fruit, and compare them with the sections of buttercup fruits. What evidence have you that the fruit of blackberry or raspberry is a collection of drupes? What is the little thread on each? What sign of a similar structure is to be seen on a plum or cherry?

4. Many-seeded dry fruits.—(*a*) Compare the single unripe carpel of the pea with one of the several carpels of an unripe fruit of marsh marigold or monkshood. Draw and describe the different methods by which the ripe *legume* of the pea and the ripe *follicles* of marsh marigold and monkshood open to shed the seeds.

(*b*) *Capsules.*—Collect ripe fruits of wallflower, shepherd's purse, iris, bluebell, violet or pansy, campion, primrose, poppy, harebell, snap-dragon, pimpernel, plantain, etc., and make drawings to show how the seeds are liberated in each case. All these fruits are capsules. In what respects do they resemble each other?

5. Berries.—Make transverse sections through ripe and unripe fruits of gooseberry, cucumber, tomato, orange, grape. In what respects do all these berries differ in structure from a drupe? Frame a definition of berry.

Fruits.—Fruits seem at first sight bewildering in their variety, but when their development is followed from the flowers through the various stages of ripening, most of them are found to fall into one or other of a few groups, each group showing well-marked features in common. Let us once more take the buttercup as our starting-point.

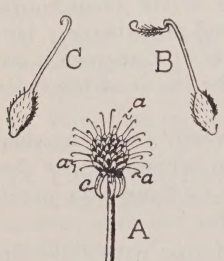


FIG. 225.—*A*, Aggregate Fruit of Wood Avens (nat. size); most of the stigmas have broken off. *a, a, a*, achenes with stigmas still attached; *c*, calyx; *B*, single achene with stigma still attached (magnified); *C*, single hooked achene after loss of stigma (magnified). (T. D. Tuton Hall.)

Achenes.—The fruit of the buttercup or of avens (Fig. 225) is said to be compound because, being developed from an apocarpous gynaecium, it consists of a number of separate ripened carpels. Each of them is called an achene, and the whole fruit is a *collection of achenes* on a dry thalamus. The term achene is applied to any **dry, separate, one-seeded** ripe carpel. The papery or leathery pericarp (ovary wall) of an achene does not open (or "dehisce") to liberate the seed inside it, but rots when the seed germinates. An achene is therefore said to be **indehiscent.** The achenes of elm, ash, birch and sycamore have the pericarp extended to form a flat plate (wing), and are called *samaras*.

The fruit in the Compositae (p. 406) is a single achene, to which a plume-like calyx often adheres (Fig. 286); the achene of the sunflower (p. 8), daisy and various other Compositae has no attached calyx. A grain of wheat or maize is an example of the characteristic achene, which is the fruit of the grass family; in it the seed-coat and pericarp are fused together; that the grain is a fruit and not merely a seed is shown by the presence of either the stigmas or their scar at the upper end.

A *nut* (*e.g.* acorn, hazel nut) is an achene with a woody pericarp (shell).

Schizocarps.—Achenes are sometimes formed by the splitting apart, when ripe, of one-seeded carpels which in the flower were united. This is well shown in the sycamore, the fruit of which (Fig. 1) is a pair of winged achenes (samaras) formed in this way. Similarly, in cleavers (Fig. 234) and the Umbelliferae (Fig. 269) two, in the geraniums five (Fig. 239), and in the mallow many, achenes are formed by the splitting of a syncarpous ovary into one-seeded parts. Fruits of this kind are called schizocarps (splitting fruits). The ripe fruit of the dead-nettle and of the radish also breaks into portions containing one seed each, but these are not strictly achenes, since each is not a complete carpel. Such splitting should not be confused with true dehiscence, which liberates the actual seeds.

Drupes.—It is interesting to contrast a nut or other achene with the fruit of the plum or cherry (Fig. 226). The chief

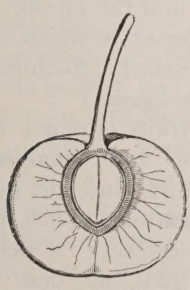


FIG. 226.—Drupe of Cherry. (After Figuier.)

FIG. 227.—Fruit of Blackberry, consisting of a number of drupes.

difference is that, in the latter, part of the pericarp is juicy (succulent). Such a fruit, called a drupe, consists of (*A*) the

pericarp, in three distinct layers: (*a*) an outer skin (*epicarp*), (*b*) a juicy middle portion (*mesocarp*), (*c*) a woody lining or "stone" (*endocarp*), and (*B*) the single seed. It will be noticed that the "shell" of a nut corresponds not merely to the stone of a cherry, but to stone + pulp + skin.

The fruit of the blackberry or raspberry is compound, consisting of a *collection of small drupes* on a dry thalamus, and therefore bears the same relation to a buttercup fruit that a cherry bears to a nut.

Dehiscent and indehiscent fruits.—In almost all cases a one-seeded fruit is indehiscent; it reaches the ground with its seed enclosed in a more or less complete pericarp, which decays to liberate the embryo on germination (Fig. 21). When, on the other hand, many seeds are enclosed in one pericarp, it is to their advantage that they should be shed separately, for they will then be less likely to crowd each other. With *dry*, many-seeded fruits, this is accomplished by dehiscence (self-opening) or by "splitting" (p. 353); with *succulent* fruits it is usually brought about by animals (*e.g.* birds), which eat the juicy pulp and scatter the seeds.

Dehiscent dry fruits.—A ripe pea pod is an excellent example of a many-seeded dry fruit. It is simple, being formed from **one carpel**, and dehisces by cracking open along two lines, viz. the midrib and the line of union of the margins to which the seeds are attached. Such a fruit is called a *legume*.

Fig. 228.—Follicles of Monkshood, before and after dehiscence. (After Strasburger.)

The fruits of marsh marigold, larkspur and monkshood are compound, since the gynaecium was **apocarpous**. Each ripe carpel resembles a legume except in one respect: it dehisces by separation of the margins only (Fig. 228), and does not open along the midrib. It is called a *follicle*, and the whole fruit is a collection of follicles.

Syncarpous dry fruits are called *capsules*. Crucifers (p. 376) usually have a bicarpellary fruit called a *siliqua* or (if short and

wide) a *silicula* (Fig. 249, *A*, *C*); but most capsules are composed of three or five carpels. Capsules dehisce when ripe by splitting of the pericarp in various ways, or by the opening of pores (Fig. 237).

Berries.—Syncarpous fruits, of which *all* the pericarp except the outer skin becomes succulent, are called berries. They are thus quite different from drupes, in which part of the pericarp is woody. The seeds of some berries (*e.g.* grapes), however, develop hard seed-coats. Berries are usually many-seeded, but the date has a one-seeded berry; its hard "stone" is the endosperm of the seed; the embryo is a very small structure at one side of the endosperm, and the seed-coat is a thin skin; the edible pulp surrounding the seed is pericarp. Familiar and more normal examples of berries are gooseberry, currant, bilberry, honeysuckle, grape, orange, tomato, cucumber, etc. Bananas are seedless berries, the plants being propagated vegetatively.

FIG. 229.—Berries of the Currant. (After Figuier.)

Superior and inferior fruits.—A flower with a *superior* gynaecium naturally gives rise to a superior fruit, which often shows the remains of the calyx at the stalk end, and the scar, or remains, of the style (or even of the stigma) at the opposite end (*e.g.* pea, cherry, blackberry, orange, wheat).

If the gynaecium is *inferior*, the resulting fruit is also inferior, and in such cases the stalk and the remains of the calyx are often to be seen at opposite ends (*e.g.* gooseberry, bilberry, dandelion, sunflower). It will be readily understood (p. 327) that the outer portion of an inferior berry or achene is derived from the thalamus.

Special kinds of fruits.—Many plants of the rose family (p. 387) have fruits the bulk of which consists of thalamus. The fruit of the strawberry is a collection of small yellow achenes on the *outside* of a greatly swollen and juicy thalamus; while a rose-hip is a collection of achenes adhering to the *inside* of a swollen thalamus, so deeply cup-shaped that the calyx is at

the top. In the apple, pear, quince and mountain ash the fleshy thalamus is more or less completely closed in at the top, where the calyx and the remains of the styles may be seen; these fruits (called **pomes**) are distinguished from inferior berries by the fact that the pulp is chiefly thalamus and not chiefly pericarp; the pericarp forms the horny seed-cases of the "core." In the hawthorn the pericarp becomes woody.

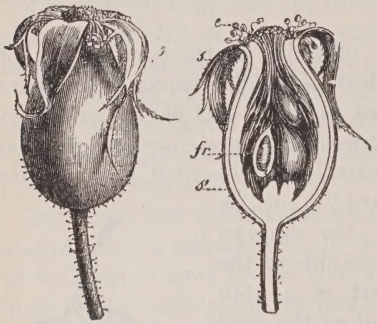


FIG. 230.—Fruit of Rose, consisting of the fleshy hollowed axis *s'*, the persistent sepals *s*, and the carpels *fr*. The stamens *e* have withered. (After Duchartre.)

Certain special forms of **drupe** are interesting. The almond is a drupe in which the mesocarp, instead of being fleshy, is spongy. The cocoanut is a drupe with a fibrous mesocarp enclosing air, so that the complete fruit floats on water and is thus distributed. The walnut also is a drupe, the shell being the endocarp; the fleshy part outside is not palatable, and is removed before the so-called "nut" is offered for sale. The brazil-nut is not a fruit, but a seed only, the shell being the seed coat.

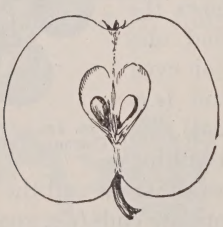


FIG. 231.—Fruit (pome) of Apple, cut in half vertically. (After Strasburger.)

FIG. 232.—Infructescence of Mulberry (*Morus nigra*) bearing a number of small drupes. (After Duchartre.)

The pineapple, fig and mulberry are not derived from single flowers, but are the final products of whole inflorescences. They are therefore sometimes called **infructescences** instead of fruits.

44. FRUITS AND THE DISPERSAL OF SEEDS.

PRACTICAL.

1. Succulent fruits.—Study the succulent fruits mentioned in the previous section, as well as any others you can find, and try to discover by observation how their seeds are usually scattered. **Do not taste any unknown fruits.** With this precaution observe and note the following points in each case : (*a*) Compare the *taste* of the unripe and ripe fruit ; (*b*) Compare the *colours* of the unripe and ripe fruit ; which is more conspicuous ? (*c*) How are the seeds of the ripe fruit protected from being injured by the animals eating the pulp ?

Preserve a good specimen of each kind in a 2 per cent. solution of formaldehyde (made by diluting 1 volume of " formalin " to 20 volumes with water).

2. Hooked fruits (burs).—Collect specimens of fruits of the following plants, and keep them, dry, in a box for reference and study : corn buttercup, cleavers (goosegrass), avens (herb bennett), agrimony, forget-me-not, wild carrot, enchanter's nightshade, bur marigold, teazle, burdock. Look for other hooked fruits. Try to find out which part of the fruit is hooked. Are these tall or low plants ? Would such hooks be more useful on the fruits of tall or low plants ?

3. Winged fruits and seeds. (*a*) *Fruits.*—Collect and preserve the following dry fruits : ash, elm, sycamore, birch, lime, hornbeam, dock.

Compare the time of falling of an uninjured specimen with that of one from which the " wing " has been removed.

(*b*) *Seeds.*—Shake out the seeds from the ripe cones (fruits) of pine, fir, larch. Experiment with them as above. Notice also the flat plates on the seeds of honesty, field spurrey and yellow rattle.

4. Plumed fruits and seeds. (*a*) *Fruits.*—Compare the plume (modified *calyx*) of achenes of dandelion, thistle, groundsel and various other Compositae, with the plumed *style* of a clematis achene. Compare the plumed achenes of cotton grass (moors) and bulrush (swamps). How do these various achenes keep " right side up " in the air ? Breathe very gently on a settled dandelion fruit, and study its behaviour in air which is alternately moist and dry. Does it thereby work its way through the grass to the soil ?

(*b*) *Seeds.*—Open the fruits (capsules) of willow, poplar and willow-herb, and observe the behaviour of the hairs on the seeds according as the air is damp or dry. How are the seeds dispersed ?

5. Self-sowing arrangements.—(*a*) Bend the stiff stalks of the following plants (when in fruit) to one side and then release them : poppy, harebell, primrose, foxglove, campion, plantains, monkshood. Notice the scattering of the seeds.

(*b*) Warm ripe fruits, not yet dehisced, of the following before a fire, and describe the result : sweet vetch, pea, gorse, field geranium, storksbill (or garden geranium), violet (or pansy), wood sorrel. Watch the behaviour of the five portions, into which the fruit of the storksbill or garden geranium splits, in damp and in dry air, when placed on grass or cotton wool. What is the use of the barb at the bottom of the achene ? Compare the action of the bristle-like awn on an oat grain.

The need for seed dispersal.—It should be borne in mind that all the beautiful complexity of structure and behaviour of flowers and fruits, growing undisturbed by man, are directed to one supreme object—the production and efficient planting of healthy seeds. The seed being clearly the all-important part of every fruit, from the plant's " point of view," we must see how the other parts of the fruit help the seed to reach a place suitable for germination. In the previous section we studied the construction of the machinery ; we must now observe it at work.

It is obvious that out of, say, a hundred seeds produced by a certain plant, a greater number will germinate successfully and become vigorous plants in their turn, if they are scattered far and wide, than if they all fall close together on the ground beneath the parent plant. For, in the first case, though many would no doubt fall in places unsuitable for germination, some would almost certainly have better luck ; while in the second case, where the seeds were not scattered, the whole hundred—all needing the same conditions—might easily perish from overcrowding, lack of light, etc. (Fig. 359).

Succulent fruits.—Nearly all fruits which are juicy when the seeds are ripe are **edible,** and attract birds or other animals able to scatter the seeds. Birds—blackbirds and thrushes, for example—are very fond of the various drupes and berries, rose

hips, haws, strawberries, apples, etc., the fruits of mistletoe, holly, elder and yew, and carry them away to consume at leisure. The birds eat the sweet, fleshy pulp, but the accompanying **seeds are protected** from harm. The seed of such a drupe as a cherry, for example, is enclosed in the woody endocarp (stone) which is dropped by the bird. The seeds of the rose-hip (Fig. 230) are enclosed in hairy achenes, which are rejected, and therefore scattered, because they irritate the birds' mouths unpleasantly. Some seeds (*e.g.* orange pips) are very slippery, and shoot to a distance when grasped. The seeds of currants and similar fruits have hard seed-coats, and those of strawberries are in horny pericarps, so that even if they are swallowed, they are not digested, but pass through the birds' bodies unharmed. When such seeds are dropped they are no worse for their experience—some are actually helped by it to germinate—and with good luck grow into healthy plants. Mistletoe seeds are wiped from the birds' beaks on the branches of trees, where they germinate (p. 229). Ants are said to be very fond of the fleshy aril on the gorse seed, and thereby tempted to disperse the seed.

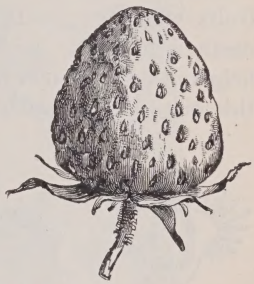


Fig. 233.—Succulent receptacle of Strawberry as a bait for birds. (After Figuier.)

Juicy fruits are almost always very **conspicuous** as well as pleasant to eat, *when the seeds are ready for scattering*, but not before. The ripening fruit is made conspicuous by changing from green to a colour which shows up distinctly against the foliage of the plant. Most commonly the ripe fruit is red, red contrasting most strongly with the green background of leaves. When the leaves become brown or reddish as the fruit ripens, the latter is often blue or black (wild cherry, blackberry, bilberry, elder, etc.).

Not only are the seeds always protected from injury by the animal's teeth, bill or digestive juices; even the ripe pulp is more or less protected from the weather, from damage by mould, and from being eaten by such animals (*e.g.* wasps

and other insects) as are not strong enough to scatter the seeds. Thus the sweet orange pulp is covered by a rind which contains an irritating oil, very unpleasant to insects; gooseberries are hairy; grapes, plums, peaches and cherries have a waxy "bloom" on the surface; apples have a thin layer of cork below the skin.

Hooked fruits or burs.—We now come to a second group of fruits which get scattered by animals, though by a different means; for these fruits "steal a ride," instead of bribing their helpers to carry them to a fresh place. An excellent example of this method is afforded by the herb-bennet or wood avens, the

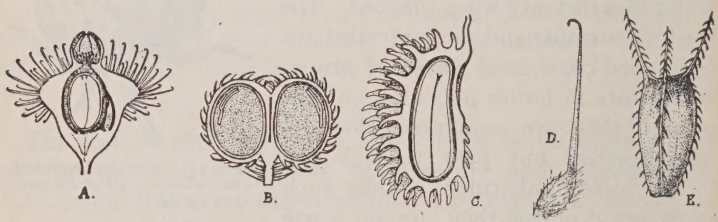


FIG. 234.—Fruits with hooked outgrowths, effective in transfer by animals. *A*, Agrimony; *B*, Cleavers; *C*, Houndstongue; *D*, Avens; *E*, Bur Marigold. All magnified. (After Le Maout.)

flowers of which are sometimes mistaken by careless observers for buttercups. The fruit (Fig. 225) is a collection of achenes, the stigmas of which break off when the seeds are ripe, leaving a sharp little hook at the end of each style. Human beings, dogs, sheep or cattle are very likely to brush against such plants and carry off the achenes on their clothing or hair. Thus the seeds may be carried far from the place where they grew before they reach the ground. In agrimony (rose family) the hollow thalamus, containing two achenes, is hooked; in cleavers (goosegrass) and also in the wild carrot, the fruit is a schizocarp, splitting into two hooked achenes. In the bur marigold (a composite growing in marshes) the calyx (corresponding to the plume of a thistle) surmounting each achene consists of barbed stiff bristles; while in the related burdock each bract of the involucre below the head becomes hooked. The seeds of many other plants are similarly dispersed by "bur fruits."

It is evident that such hooks would be useless if the fruits

grew out of the reach of animals. As a matter of fact, the plants bearing them are almost invariably low-growing.

Wind dispersal.—Many plants depend on the wind for the dispersal of their seeds, and in such cases either the seeds themselves, or the fruits which contain them, are provided with outgrowths of various kinds, which increase the surface greatly

Photo. Henry Irving.

FIG. 235.—Ash twigs in autumn, with winged fruits.

without adding much to the weight. Acting like parachutes, such outgrowths offer increased resistance to the air, and therefore prevent the seeds from falling quickly to the ground. Thus, any breeze which is blowing is likely to carry them to some distance.

Winged fruits and seeds.—Certain **fruits** have the pericarp prolonged to form a flat plate or "wing." Among trees, this is well seen in the winged achenes (samaras) of sycamore (Fig. 1) and other maples, ash (Fig. 235), elm (Fig. 325) and birch (Fig. 334). The wing naturally delays the fall of such a fruit, and thus provides time for any wind to carry it away, while each group

of fruits of the lime tree is similarly dispersed by help of a leafy bract (Fig. 321) and the fruit of the hornbeam by a trilobed bract (Fig. 218, 7). The **seeds** themselves, of pines, firs and larches, have each a thin, papery wing (Fig. 347, *B*) which is useful in the same way.

Heavy fruits or seeds can only be dispersed in this manner when they are borne by fairly high trees ; if they were formed on low plants they would fall to the ground long before the wind could catch them properly, and their wings would be useless. Even low plants, however, find wings a help when their fruits or seeds are small and light. The achenes of the dock have three wings (the remains of the perianth), and the achenes of many Umbelliferae are also winged. Among winged *seeds* are those of honesty, field spurrey, yellow rattle, many lilies and some orchids.

Plumed fruits and seeds.—The **fruit** of the dandelion (Fig. 286) provides one of the best possible examples of wind dispersal. The head (*capitulum*) of small strap-shaped flowers is succeeded by a globular head of achenes, each surmounted by a hairy calyx (called a *pappus*), which forms a beautiful little plumed parachute. One by one the tiny fruits are blown off the flat top of the flower-stalk and carried away by the breeze, being kept "right side up" by the weight of the seed at the bottom. When at last they settle to the ground, the varying dampness and dryness of the air causes the plume to shut up and expand in turn ; and the movements, aided by the upward-pointing spikes on the achene (Fig. 286, *3*), force the fruit through the grass to the soil. Thistles, groundsel, coltsfoot and a great many other relatives of the dandelion have fruits of a somewhat similar kind, which may often be seen floating through the air in summer. The so-called cotton-grass (p. 278) and bulrush have achenes bearing tufts of hairs which serve a similar purpose. The achenes of traveller's joy or old man's beard (wild clematis) have long and hairy styles (Fig. 236), and are therefore easily dispersed by the wind.

Fig. 236.—Single achene of Clematis (enlarged).

In some plants the **seeds** themselves become hairy, so that they

are blown away when the fruit opens. Among trees, willows and poplars use this method; the willow herbs probably owe their name (for they are not related to the willow trees) to a similar habit. Cotton, which is manufactured into cloth, consists of hairs covering the seeds of the cotton plant; their original use is to disperse the seeds.

The censer mechanism.—We come next to cases in which ripe fruits open or dehisce just sufficiently to let the seeds be thrown

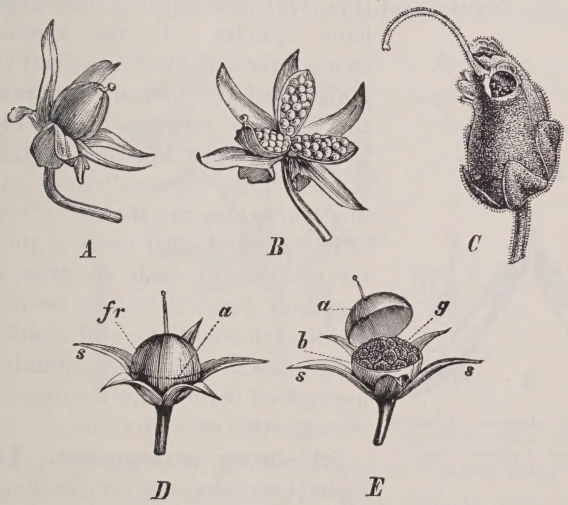


FIG. 237.—Modes of dehiscence of capsular fruits. *A B*, capsule of Pansy before and after the dehiscence; *C*, poricidal capsule of Snapdragon (magnified); *D, E*, pyxidium of Scarlet Pimpernel before and after dehiscence. (After Strasburger.)

out by the jerking or even swaying of the stiffened stalk. As the poppy fruit (Fig. 158) becomes ripe, a line of small holes opens round the side, just below the flattened top. The small seeds at the same time break off their stalks and lie loose in the hollow "poppyhead." As this sways about in the wind, the seeds are shaken out, a few at a time, through the holes and so sprinkled separately on the ground, or even blown considerable distances, since they are quite light. This method of scattering seeds is sometimes called the censer mechanism. In the Campanulas (harebell, etc.) a similar arrangement is

found, but the holes in this case open at the *base* of the capsule, which comes to be uppermost in the hanging ripe fruit. The top of the capsule of the campion and its relatives, and the primrose, breaks into a number of teeth which curl outward in dry air (liberating the seeds if the stalk be shaken) but inward when the air is moist. The snap-dragon fruit (Fig. 237, *C*) has three holes, guarded by teeth which act similarly. The pimpernel (*D* and *E*) and plantain capsules open by a lid which breaks off. Monkshood (Fig. 228), larkspur and marsh marigold have follicles. In the siliqua (the characteristic fruit of crucifers) the two portions of the pericarp separate from the bottom upwards (Fig. 249, *A*), leaving the seeds attached to the edges of the "false septum," from which in due course they are shaken by the wind.

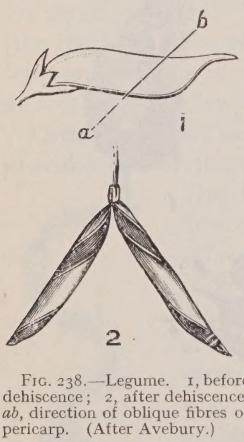


FIG. 238.—Legume. 1, before dehiscence; 2, after dehiscence. *ab*, direction of oblique fibres of pericarp. (After Avebury.)

In these and other cases of the censer mechanism, the seeds are often shot to a greater distance by the bending and sudden release of the stiff elastic stalks —by gusts of wind or by animals brushing against them—and the arrangement is suggestive of a catapult.

Self-sowing arrangement.—The **pea family** (Leguminosae) commonly sow their own seeds by the twisting of the halves into which the pericarp of the ripe fruit (legume) divides (Fig. 238). The twisting is due to shortening of the oblique fibres (easily seen in a half-ripe pea pod) of the inner layer of the pericarp. The result is that the seeds are screwed or wrung off, and fall to the ground. In the gorse and some other Leguminosae this takes place so suddenly that the seeds are thrown to a distance of a yard or more.

In the **geranium family** the fruit (a schizocarp) consists of five carpels arranged round a central column (*A*, Fig. 239). When the seeds are ripe, the carpels suddenly spring from the rod. In some cases (cranesbill, field geranium) the five seeds, being released at the same time, are flung into the air, as from a sling,

by the flick of the carpels (*B*, Fig. 239). In the storksbill each carpel becomes entirely detached, and the style coils up in dry air, but straightens in moist air, thus gradually forcing the ovary, with its contained seed, into the soil. [The "awn" (p. 419) of certain grasses behaves similarly.] Wood-sorrel, nearly related to the geraniums, has a fruit (Fig. 130) very similar in most respects. Each of the five carpels opens by a split, letting out the contained seeds, two or three in each. The outer skin of the seed itself is very elastic, and suddenly gives way under the strain, turning inside out, and shooting its contents to a distance.

FIG. 239.—Field Geranium. ($\times \frac{1}{4}$.)

The ripe, egg-shaped fruit of the **violet** and pansy (Fig. 237, *A*) splits down the side along three lines, and is thus divided into three boat-shaped valves (each holding seeds) which bend back as shown in Fig. 237, *B*. Then the curved sides of each valve gradually straighten, leaving less and less room for the hard, smooth seeds inside. As the pressure of the sides becomes greater and greater, the seeds are shot out, one by one, to a considerable distance.

Seed dispersal by water.—The complete cocoanut fruit (p. 356) has a layer of matted fibres which, because of entangled air, buoys it up in sea-water and enables it to be transported along the shore or perhaps to another island, where the seed will eventually germinate. Certain British plants are similarly dispersed by floating seeds (*e.g.* white water-lily, the seed of which has a

spongy aril containing air) or fruits (the fruit of yellow water lily breaks up into separate spongy carpels, which float; alder has floating achenes).

EXERCISES XVIII.

1. Briefly describe the changes that take place in the flower of specimen C as they grow from the bud to the oldest stage represented on your specimen.
[C. For each candidate, enough buttercup inflorescence of one species to represent stages from the flower bud to the fruit.]
(J.M.B. Sch. Cert.)

2. Organs of fruit or seed-dispersal originate from different parts of the flower. Illustrate this statement as fully as you can, sketching the examples you mention. (L.M.)

3. Make labelled drawings of specimen B, and describe it concisely. [B = Willow.] (C.J. July.)

4. Write a short account of the part played by the wind in the distribution of fruits and seeds. Illustrate your answer by a careful description of the structure of *five* examples drawn from British plants. (O.S.)

5. Describe *three* examples of native plants distributed by animals. Show what structures are used, and how distribution is effected in each case. (J.M.B. Hr. Sch. Cert.)

6. Write a short account of the part played by animals in the distribution of fruits and seeds. Illustrate your answer by a description of *five* examples of fruits of British plants. (O.S.)

7. Describe with the aid of drawings the specimen K. [K = fruit of rose.] (C.J. Dec.)

8. Make drawings of the specimen provided (*a*) in external view and (*b*) in longitudinal section (much enlarged). Label the different parts, and point out what changes have occurred since the fertilisation of the ovules. [Rose hips.] (J.M.B. Matric.)

9. Make diagrams to illustrate the structure of the specimens A and B provided, and name the parts of your drawing.
(A = rose hip, B = poppy capsule.) (O.S.)

10. Illustrate by means of diagrams the structure of the fruit of any *five* of the following plants, naming the various parts: strawberry, plum, apple, lily, pea, poppy, dandelion. Show, in each case, whether the fruit is formed from an inferior or a superior ovary. (O.S.)

11. Select *four* of the following plants. Describe the structure of their fruits and, with the aid of diagrams, show in each case

the parts of the flower concerned in the formation of the fruit : clematis, apple, cranesbill (*Geranium*), rose, blackberry, Canterbury bell (*Campanula*). (O.S.)

12. Give a careful account of the changes which occur in the flower leading to the formation of the ripe fruit in any *two* of the following : rose, dandelion (or other member of Compositae), bean, wallflower (or other member of Cruciferae). (C.S.)

13. Describe the fruits of the poppy, dandelion and hawthorn, and explain in each case how the seeds are dispersed.
(J.M.B. Matric.)

14. Describe the structure of the fruit of the rose, poppy, gooseberry and cherry, and in each case show, with the aid of diagrams, the parts of the flower concerned in the formation of the fruit. (O.S.)

15. Describe the fruit (as understood by the botanist) of the following : strawberry, blackberry, orange, fig, bean.
(J.M.B. Jun. Cert.)

16. Describe the adaptive parts and arrangements by which the seeds and fruits of the following are dispersed : (*a*) the dandelion, (*b*) the elm, (*c*) the sycamore, (*d*) the burdock, (*e*) the goosegrass, (*f*) the cherry. (J.M.B. Sch. Cert. and Matric.)

17. Account for the prevalence of any three of the following common weeds : dandelion, coltsfoot, thistle, bind-weed, creeping buttercup. Illustrate your answer by sketches, showing how the types selected multiply and spread. (Cert.)

18. Describe and compare carefully the three fruits provided. Make a diagram showing the appearance of each fruit as seen in median longitudinal section. (J.M.B. Hr. Sch. Cert.)

19. Write a short essay on the dispersal of seeds.
(J.M.B. Sch. Cert.)

20. Define, and sketch, a familiar example of five of the following : rhizome, pome, rosette-plant, follicle, halophyte, dichasial cyme. (L.M.)

CHAPTER XIX.

SOME COMMON FAMILIES OF FLOWERING PLANTS.

45. THE PRINCIPLES OF CLASSIFICATION.

PRACTICAL.

1. Species of buttercups.—Gather as many kinds of yellow buttercup as you can find,* and examine them to determine whether (*a*) the *leaves* are divided or entire, (*b*) the *achenes* are smooth or rough, (*c*) the *calyx* is spreading or bent back (reflexed), (*d*) the *flower stalk* is furrowed or round, hairy or smooth, (*e*) the *nectary* (p. 318) is naked or covered by a scale. Group together buttercups which are alike in *all* these respects. The buttercups in each group are said to be of the same *species*.

Sow ripe achenes from buttercups of various species, having previously made a note of the characters of the parent of each (or having learnt its name), and see if the resulting plants are similar to their parents in *a*, *b*, *c*, *d*, and *e*.

2. Buttercups and their relatives.—Assuming that all the above flowers are buttercups, make a list of the features which buttercups have in common. Note that water buttercups are white. Explain why (*a*) *clematis* (traveller's joy) (fl. July-Aug.), (*b*) *marsh marigold* (fl. March-June), and (*c*) *wood anemone* (fl. April-May) cannot also be considered buttercups.

3. The buttercup family.—*Compare* buttercups, anemones, clematis, marsh marigold, globe-flower (May-June), hellebore ("Christmas rose," March-May), winter aconite (Feb.-April), columbine (May-June), larkspur (June-July), monkshood (July-Aug.), when in flower. (The months named are for the wild flowers. Cultivated specimens can often be obtained earlier.) In what

* In spring only the goldilocks and lesser celandine are common. In summer, several other kinds are in flower.

characters of leaf venation, and of number, position and cohesion of sepals, petals, stamens and carpels, do these plants resemble each other ?

The meaning of classification.—In the foregoing chapters it has been assumed that the reader knows a number of common plants by name—that such words as buttercup, daisy, wheat, oak, etc., have a definite meaning for him. It is generally understood that a buttercup (for example) has certain features which it shares with all other buttercups, and in respect of which it is different from all plants which are not buttercups. A similar statement could be made of any other kind of plant. This being the case, it should be possible to sort plants into groups—all the plants in any group being more or less alike; and with closer examination, differences between the plants of any such group would no doubt be found which would make it possible to divide the group into smaller groups. Such "sorting" of things—in this case plants—is called **classification.**

The most satisfactory classification of plants would be one which grouped together those most nearly *related* to each other *by descent*, in the sense that two men are more closely related to one another if they had the same grandfather, than two men who had had no ancestors in common since the Stuart period. In general, the closer relationship of the first two men would show itself in a greater resemblance between them. Similarly, it is to be expected that closely-related plants will resemble each other in certain essential respects which are least likely to change from generation to generation.

We saw in Chapter XIV. that leaves, stems and roots of certain plants become very different when under different conditions of moisture, light, temperature, etc. On the other hand, similar conditions of life produce certain structural resemblances between plants not nearly related; compare, for example, crowberry and heather (Fig. 172). Such conditions, however, affect least of all the structure of the flowers of the plants mentioned, and therefore the **flowers are the safest guides** to the classification of the plants possessing them. Nevertheless certain vegetative characters (*e.g.* venation of leaves, etc.) are also remarkably constant, and are helpful in classification.

Species, genus and family.—Let us apply these ideas to the classification of **some common buttercups.** The colour of the white "*water buttercups*" (Fig. 188) enables us at once to set them apart. The yellow buttercups can be sorted into two sets, (*a*) those with entire leaves, (*b*) those with much-divided leaves. Set (*a*) includes, among others, (i) the *spearwort buttercups*, which

Photo. Henry Irving.

FIG. 240.—Goldilocks Buttercup (*Ranunculus auricomus*).

flower in summer and have long narrow leaves, and (ii) the *lesser celandine* (Fig. 139), which flowers in spring and has cordate leaves. The buttercups of set (*b*) are often called the *crowfoots*, from the shapes of the deeply-divided leaves. Some of the crowfoots have spreading sepals, others reflexed sepals. Some have smooth achenes, others rough achenes. In some the nectary at the base of each petal is naked; in the others it is covered by a scale. Some have a furrowed flower-stalk, others a round flower-stalk. But if we find that certain of our specimens are

like each other in *all* these respects, but different from the rest in some—perhaps only one—respect, then these specimens ought evidently to be given some distinguishing name in addition to buttercup.

Thus certain yellow crowfoot buttercups (Fig. 240) have always deeply-divided leaves, smooth achenes, a spreading calyx, an unfurrowed flower stalk, and a naked nectary on each petal, but are different in at least one of these characters from all other buttercups. They are called *goldilocks buttercups* in allusion to their bright colour. Other very common buttercups (Fig. 242) are like goldilocks in all but one of the characters mentioned above: in them the nectary is covered by a scale. They also are therefore given a special name, the *bitter buttercup*, from their taste when chewed.* The "*bulbous*" *buttercup* (Fig. 241) has the nectary covered by a scale, but its sepals are reflexed. Similarly, several other kinds of buttercup have each features in common, but do not agree in all respects with any of these three; each kind must have a name of its own.

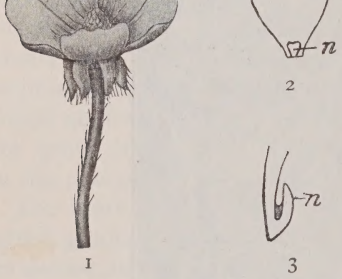


FIG. 241.—*Ranunculus bulbosus*. 1, flower; 2, front view of petal, showing nectary (*n*); 3, side view of base of same, enlarged. (After Avebury.)

Each kind constitutes a **species** † of buttercup. Thus the goldilocks buttercups form one species, the bitter buttercups another species, the bulbous buttercups a third species, the lesser celandines a fourth, and so on. They all belong to the **genus** ‡ buttercup or *Ranunculus*. The botanical name of a plant is expressed by two Latin words, the name of the genus being written first, with a capital initial, the name of the species second, usually with a small initial. Thus the botanical name of the goldilocks buttercup is *Ranunculus auricomus*, that of the bitter buttercup is *Ranunculus acris*, that of the bulbous buttercup is *Ranunculus*

* The juice should not be swallowed.

† Plural also *species*. ‡ Plural, *genera*.

bulbosus, and so on. When there is no danger of misunderstanding, the genus is often indicated by its initial only, *e.g. R. bulbosus*.

Similarly, noting the features which all buttercups have in common, we can group the genus *Ranunculus* with other genera

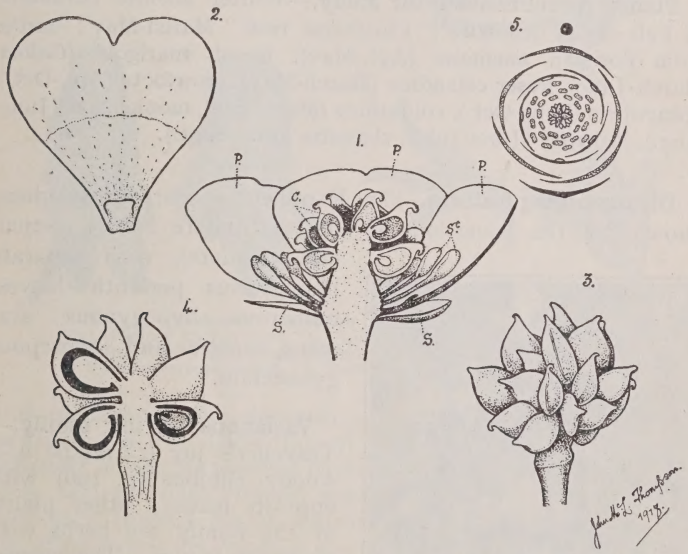


FIG. 242.—Buttercup (*Ranunculus acris*). 1, flower in median section; 2, a single petal; 3, the gynaecium; 4, the same in section; 5, floral diagram. *s*, sepals; *p*, petals; *st*, stamens; *c*, carpels. (After Thompson.)

of plants (*e.g. Anemone, Clematis*, etc., p. 374) which, though not buttercups, structurally resemble buttercups more than remaining plants do. These genera are said to belong to the buttercup family, known as the **family * Ranunculaceae.**

On the same principle, it is usual to associate the most closely related families in groups called orders. Thus, the buttercup family (Ranunculaceae), the water-lily family (Nymphaceae), the hornwort family (Ceratophyllaceae), and the barberry family (Berberidaceae) together constitute the **order Ranales.**

* The plant groups formerly called Natural Orders are now usually called Families.

46. SOME FAMILIES OF POLYPETALOUS DICOTYLEDONS.

FAMILY RANUNCULACEAE.

Plants recommended for study.—Winter aconite (*Eranthis*, fl. Feb.-Apl.), hellebore ("Christmas rose," March-May: earlier from florists), anemone (Apl.-May), marsh marigold (*Caltha*, March-June), lesser celandine (March-May), crowfoots (Apl.-Oct.), spearworts (June-Oct.), columbine (May-June), monkshood (June-Aug.), larkspur (June-July), clematis (July-Sept.).

Distinguishing features.—The Ranunculaceae are dicotyledons, shown by the venation of the exstipulate leaves (reticulate palmate), with separate hypogynous perianth leaves, numerous hypogynous stamens, superior and apocarpous gynaecium.

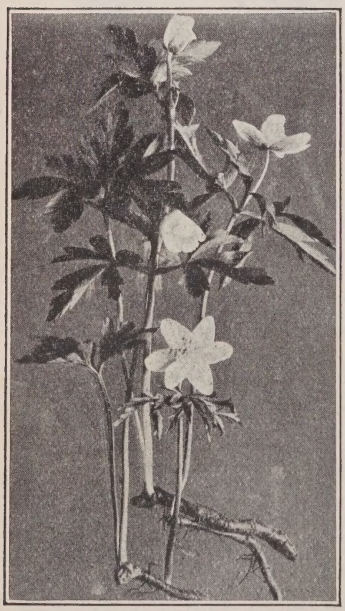


Photo. Henry Irving.

FIG. 243.—Wood Anemone.

Variations in the family.—Traveller's joy (*Clematis*) is a woody climber (p. 190) with opposite leaves; other plants of the family are herbs with alternate leaves. The **inflorescence** is solitary and terminal in anemone, a branching cyme in most cases (*e.g.* buttercups, marsh marigold), a raceme in larkspur and monkshood. **Flowers** are regular except in larkspur and monkshood. They are hermaphrodite and hypogynous (Figs. 242 and 244). In clematis, meadow rue, anemone and marsh marigold, only one set of **perianth leaves** (probably the calyx) is present; in mousetail, Christmas rose and winter aconite there are *tubular nectaries* between the stamens and the coloured calyx; these are probably modified

petals each equivalent to the lower end only of a buttercup petal. The other flowers of the family have distinct petals as well as sepals. All the petals are spurred in columbine. In larkspur

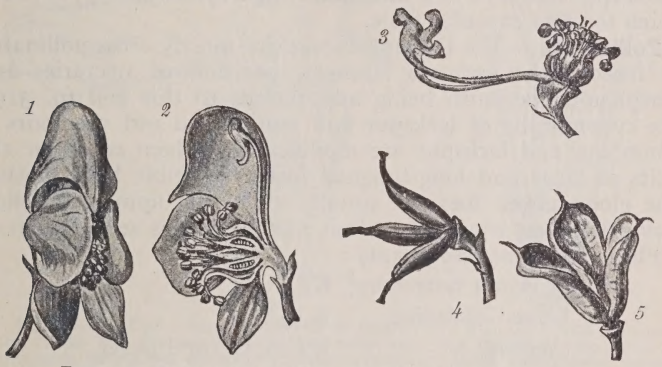


FIG. 244.—Monkshood (*Aconitum napellus*) (nat. size). 1. Flower seen obliquely from in front. 2. Flower in longitudinal section. 3. The nectaries, formed from petals, and the androecium. 4. Fruit composed of three apocarpous carpels. 5. Follicles opened. (After Strasburger.)

and monkshood the perianth is irregular (zygomorphic). In larkspur the two back (upper) petals have spurred nectaries which fit inside the spurred back (upper) sepal. In monkshood (Fig. 244) the back (upper) sepal forms a hood, covering the two back (upper) petals, which form long-stalked nectaries; the other petals are reduced in size. The numerous **stamens** are

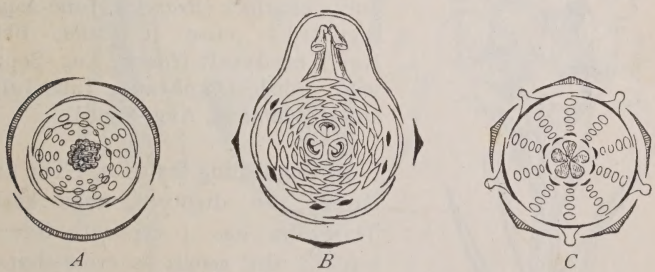


FIG. 245.—Floral diagrams of Ranunculaceae. *A*, Wood Anemone (*Anemone nemorosa*); *B*, Monkshood (*Aconitum napellus*); *C*, Columbine (*Aquilegia vulgaris*). (After Eichler.) See also Fig. 242, 5.

in most cases inserted spirally on the thalamus, and are extrorse. The **gynaecium** consists of separate carpels, which form *achenes* in anemones, clematis (Fig. 236), mousetail, buttercups and

meadow rue, but *follicles* in marsh marigold, winter aconite, Christmas rose, globe flower, columbine, larkspur and monkshood. Baneberry is exceptional in having a berry, formed from one carpel, and love-in-a-mist in having a syncarpous gynaecium which forms a capsular fruit.

Pollination.—The Ranunculaceae are mostly cross-pollinated by insects, the extrorse stamens, position of nectaries and conspicuous perianth being adaptations to this end (p. 319). The zygomorphy of larkspur and monkshood and the spurs of columbine and larkspur are modifications which cater for the visits of large and long-tongued insects (humble bees, moths). The globe-flower does not usually unfold its numerous yellow perianth leaves enough to admit insects, and is self-pollinated.

Floral formulae (see p. 321) :

Crowfoot buttercup,	$K_5C_5A_\infty\underline{G_\infty}$
Lesser celandine,	$K_3C_8A_\infty\underline{G_\infty}$
Clematis,	$K_4C_0A_\infty\underline{G_\infty}$ or $P_4A_\infty\underline{G_\infty}$
Marsh marigold,	$K_5C_0A_\infty\underline{G_5}$ or $P_5A_\infty\underline{G_5}$
Monkshood,	$K_5C_8A_\infty\underline{G_3}$.

FAMILY CRUCIFERAE.

Fig. 246.—Inflorescence of Wild Kale (*Brassica oleracea*). (After Baillon.)

Plants recommended for study.—Wallflower (*Cheiranthus*, Apl.-June), cuckoo flower (*Cardamine*, Apl.-June), hedge mustard (*Sisymbrium*, June-July), charlock (*Brassica*, June-Aug.), shepherd's purse (*Capsella*, Feb.-Nov.), candytuft (*Iberis*, Aug.-Sept.), wild radish (*Raphanus*, June-July), stock (*Mathiola*, Aug.-Sept.).

Distinguishing features.—The Cruciferae are dicotyledonous herbs. The **calyx** has 4 separate inferior sepals; the **corolla** is cross-shaped, with 4 separate hypogynous petals; the **androecium** consists of 2+4 separate hypogynous stamens; the **gynaecium** is superior, syncarpous, bicarpellary, at first one-chambered,

afterwards bilocular by the growth of a false septum. The placentation is parietal (p. 329).

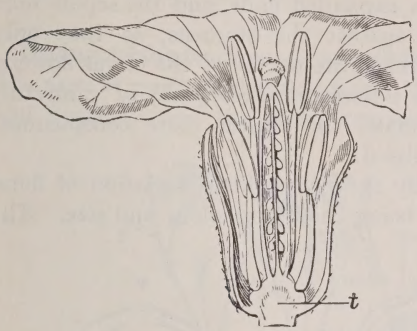


FIG. 247.—Vertical section of flower of Wallflower, two of the long stamens, as well as two petals and two sepals, having been removed. *t*, thalamus (receptacle). (After Oliver.)

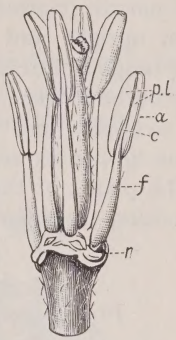


FIG. 248.—Pistil and stamens of Wallflower, the sepals and petals having been removed. *n*, nectary. (After Oliver.)

Additional features.—The **leaves** are alternate, without stipules; the venation is pinnate. The **inflorescence** is a raceme

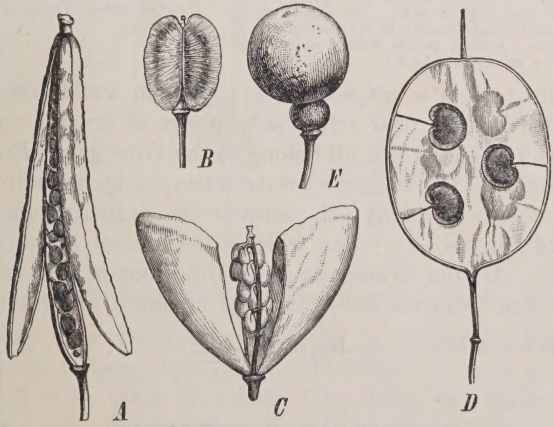


FIG. 249.—Cruciferous Fruits. *A*, Wallflower; *B*, Garden cress; *C*, Shepherd's purse; *D*, Honesty, showing the septum after the carpels have fallen away; *E*, Sea kale. (After Baillon.)

without bracts, at first often a corymb, but later lengthening to separate the fruits (Fig. 135). Nectar is produced at the base

of the two short (lateral) stamens (Fig. 248), and collects in the pouched bases of the two lateral sepals. The petals are long and narrow (clawed) with expanded ends, and the sepals hold them upright and close against the stamens, so that only long-tongued insects can reach the nectar of the larger flowers. The outer flowers of the inflorescence (corymb) of candytuft are irregular, and thus make the cluster more conspicuous. Some species are self-fertilised.

The plants of the family show very little variation of floral structure, the differences being chiefly in colour and size. The

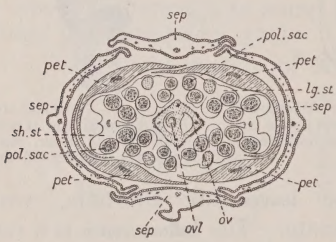


FIG. 250.—Cross-section through a Wallflower bud. *Sep*, sepals; *Pet*, petals; *lg.st*, anther of a long stamen; *sh.st*, anther of a short stamen; *pol.sac*, pollen sacs; *ov*, wall of ovary; *ovl*, ovule. (× 8.)

FIG. 251.—Floral diagram of Cruciferae. Compare with Fig. 250.

fruit (Fig. 249) is a *siliqua* (pp. 354, 364) in wallflower, stock, charlock (with its near relatives, cabbage of several varieties, turnip and swede, which all belong to the same genus *Brassica*), ladies' smock (cuckoo flower), water-cress, hedge mustard, etc.; it is a *silicula* in candytuft, penny cress, ordinary salad cress, shepherd's purse, etc.; the fruit is *indehiscent* in radish, sea kale, etc. All the Cruciferae are non-poisonous, and many, as will be seen from the above list, are common articles of food.

Floral formula : $K_{2+2}C_4A_{2+4}\underline{G_{(2)}}$.

FAMILY CAROPHYLLACEAE.

Plants recommended for study.—Greater stitchwort (*Stellaria*, Apl.-June), chickweeds (*Stellaria* and *Cerastium*, Feb.-Nov.), pearlwort (*Cerastium*, May-Sept.), corn spurrey (*Spergula*, June-Aug.), pink (*Dianthus*, June-Sept.), white campion (*Lychnis alba*, June-

Sept.), corn cockle (*L. githago*, July-Aug.), ragged Robin (*L. Flos-cuculi*, May-June), red campion (*L. dioica*, May-Aug.), bladder campion (*Silene*, June-Aug.).

Distinguishing features.—The plants are dicotyledonous herbs. The **habit of growth** is characteristic; the leaves are simple, entire and opposite, and the stems are swollen at the nodes. The

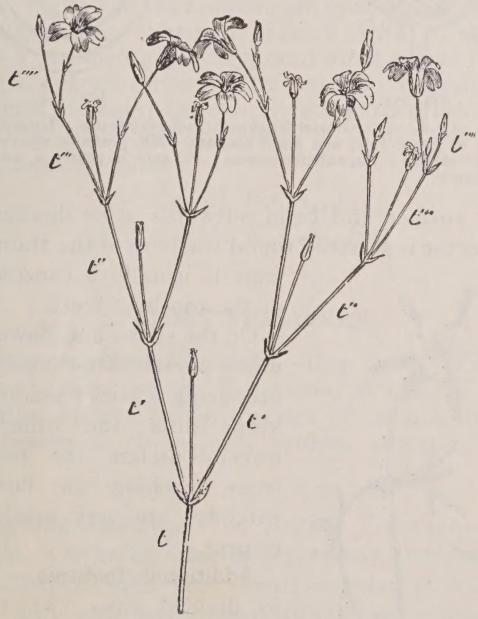


FIG. 252.—Mouse-ear Chickweed (*Cerastium collinum.*) (After Duchartre.)

inflorescence is a two-branched cyme (a dichasium, Fig. 252), which at first is very symmetrical, but often becomes somewhat one-sided in its later branches. The flower is actinomorphic. There are five inferior **sepals**; five separate hypogynous **petals**; hypogynous **stamens**, usually ten, in two whorls of 5 each, the outer whorl being opposite the petals; a superior syncarpous **gynaecium**, having 2 to 5 separate styles and an ovary with incomplete partitions, therefore one-chambered and with free

central placentation (p. 331). The flower is protandrous (p. 340), the outer stamens maturing first. The styles are stigmatic on

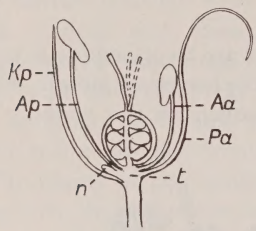


FIG. 253.

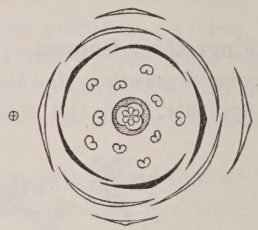


FIG. 254.

FIGS. 253 AND 254.—Greater Stitchwort (*Stellaria holostea*). Longitudinal section of flower (× 2) and floral diagram. *Kp*, posterior sepal; *Ap*, posterior stamen; *Aa*, anterior stamen; *Pa*, anterior petal; *n*, nectary; *t*, thalamus.

their inner surface and bend outwards after discharge of the pollen. Nectar is secreted round the base of the stamens. The fruit is usually a capsule, opening at the top by 5 teeth.

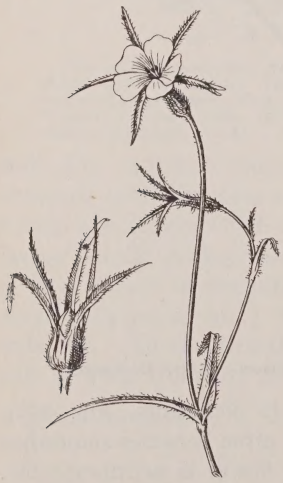


FIG. 255.—Corn-cockle. (× ½.) On the left, fruit (a capsule) enclosed in calyx. (× ½.) (After Strasburger.)

On the stems and flower-stalks of many plants of the family are hairs producing a sticky secretion, which keeps ants and other crawling insects—useless for pollination—from reaching the flowers. The catchflys are very marked in this respect.

Additional features.—The family is divided into two tribes, (A) Alsinoideae (including stitchwort, chickweed, spurrey, etc.): and (B) Silenoideae (including pinks, soapwort, campions, corncockle, etc).

Tribe **Alsinoideae.**—The calyx is *polysepalous* and the flower is shallow, the nectar being thus accessible to short-tongued insects. Stitchwort has 3 styles; chickweed, a common ephemeral weed, is usually self-fertilised and has a very variable flower.

Tribe **Silenoideae.**—The calyx is *gamosepalous* and tubular, being narrow at the top ; the petals are clawed (compare Cruciferae), with scaly outgrowths forming a fringe (*corona*), where the narrow " claw " joins the broad " limb "; small insects being thus excluded, the nectar is restricted to insects with long tongues (butterflies, moths and humble bees). White campion, bladder campion and night-flowering catchfly, *e.g.*, are moth flowers, most scented at dusk ; pinks are mostly pollinated by butterflies. White and red campion are usually dioecious (p. 341), some plants bearing only male flowers (with 10 stamens and sometimes a rudimentary ovary), and other plants only female flowers (with ovary surmounted by 5 styles ; imperfect stamens are sometimes present) ; the closely-related corncockle (Fig. 255) and ragged robin are hermaphrodite.

Typical floral formulae :

Stitchwort, $K_5C_5A_{5+5}\underline{G_{(3)}}$;
Corncockle, $K_{(5)}C_5A_{5+5}\underline{G_{(5)}}$.

FAMILY VIOLACEAE.

Plants recommended for study.—Dog violet (*Viola canina*, fl. May-Aug.), sweet violet (*V. odorata*, March-Apl., and from florists during winter), garden pansies (*V. altaica*, summer and autumn), heartsease (*V. tricolor*, gardens, summer ; and wild, May-Sept.).

Distinguishing features.—The British Violaceae—all of the genus *Viola*—are herbs. **Leaves**, net-veined, alternate ; stalked and heart-shaped with very small stipules in violets ; but lanceolate and with large lobed stipules in pansies. **Flowers** solitary and axillary, hypogynous, zygomorphic and drooping so as to face sideways. **Calyx** inferior, 5 polysepalous sepals prolonged below point of attachment to thalamus. **Corolla** hypogynous, 5, polypetalous. The odd petal is anterior and lowest in position ; it is marked by coloured streaks (honey guides) converging to the entrance of a spur into which it is prolonged at the base. **Stamens** 5, hypogynous, introrse, with very short filaments. Connectives prolonged to form triangular scales (Fig. 256, *B*, *c*) which fit close together round the style to form a conical box (Fig. 257, *P.ch*) in which pollen collects. The

two lowest stamens have backwardly-directed arms (nectaries) fitting into the spur, and secreting nectar into it, where it accumulates. **Gynaecium**, tricarpellary, syncarpous; *ovary*

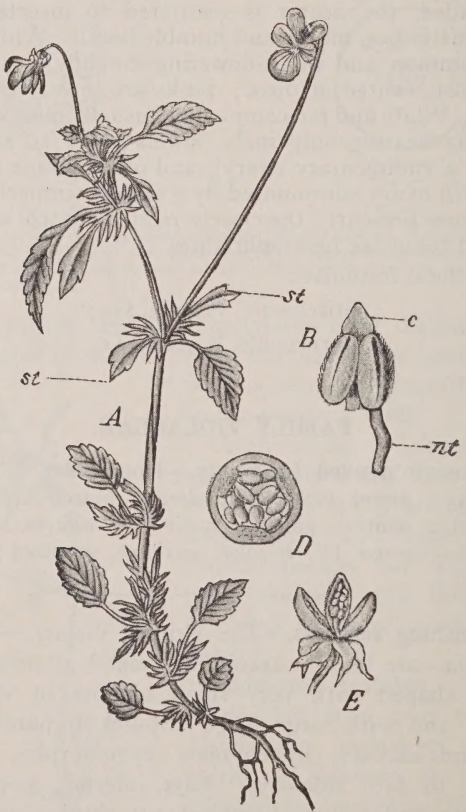


Fig. 256.—Wild Pansy (*Viola tricolor*). *A*, Entire plant (reduced); *st*, stipules. *B*, A stamen, enlarged; *c*, connective; *nt*, nectary. *D*, Transverse section of ovary. *E*, Fruit (nat. size). (After Strasburger.)

superior, unilocular, placentation marginal and parietal (Fig. 256, *D*); *style* bent, and long enough to make the stigma project in front of the anther-scales; *stigma* pointed in violets, knob-shaped in pansies. **Fruit** a capsule, opening to form 3 valves (p. 365).

Pollination.—The chief insect visitors are humble bees, which alight on the lowest petal (Fig. 257, *A.pet*). The proboscis is pushed into the spur (*sp*) in search of nectar, and first comes into contact with the stigma (*sg*), which is just above the entrance;

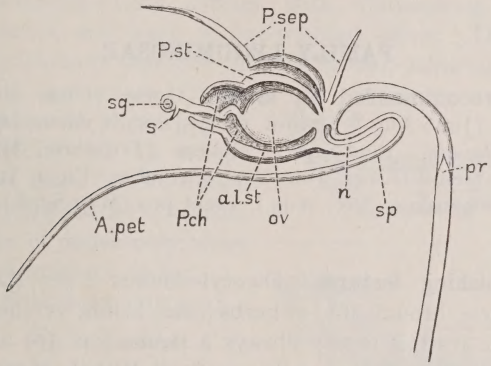


FIG. 257.—Enlarged longitudinal section of flower of Pansy. *A.pet*, anterior petal, with spur *sp*; *P.sep*, posterior sepal; *P.st*, posterior stamen; *a.l.st*, anterior lateral stamen, with nectary *n*; *sg*, stigmatic surface; *s*, scraper; *ov*, ovary; *P.ch*, pollen chamber; *pr*, prophyll (bract). An anterior lateral stamen, though not in the plane of section, is introduced for the sake of clearness. (Compare Fig. 258.)

so that if pollen is already present on the proboscis, some is likely to be rubbed on the stigma. In pansies (except the small field pansy) a small flap or "scraper" (*s*) hangs down behind the cup-shaped stigmatic surface, and the front of this also naturally receives some pollen. The disturbance of the stigma by the insertion of the proboscis shakes out some of the dry pollen from the box (*P.ch*) formed by the anther scales, and this falls on the insect's proboscis. The withdrawal of the insect pulls the scraper over the stigmatic surface and prevents self-pollination. Tufts of hairs on the two lower side-petals and on the side of the stigma of pansies, protect the nectar from insects too small to cause cross-pollination.

FIG. 258.—Floral diagram of *Viola*. (After Strasburger.)

In the spring flowers of the violets, the stamens and stigma are mature at the same time. Self-pollination, however, is rendered very improbable by their respective positions, as described above, and by the shape of the stigma; no doubt it is at times brought about by insects, and the flowers are self-fertile.

In the summer, violets produce other flowers which do not open and are self-pollinated and self-fertilised. Such flowers are described as **cleistogamic**. They are not formed by pansies.

Floral formula: $K_5C_5A\ G_{(3)}$

FAMILY LEGUMINOSAE.

Plants recommended for study.—Gorse (*Ulex*, Feb.-Aug.), laburnum (June-Aug.), broom (May-June, *Cytisus, spp.*), rest harrow (*Ononis*, June-Sept.), clovers (*Trifolium*, May-Sept.), bird's foot trefoil (*Lotus*, June-Sept.), vetches (*Vicia*, June-Aug.), peas, beans (gardens, May-Aug.), sweet pea (May-Sept.), etc.

Distinguishing features.—Dicotyledonous trees (laburnum), shrubs (gorse, broom, etc.) or herbs (peas, beans, vetches, clovers, etc.). The fruit is nearly always a **legume** (pp. 354 and 364)—hence the name of the family—and all British species have a zygomorphic flower of the form called papilionaceous ("butterfly-shaped"). The **thalamus** forms a plate or very shallow basin, the calyx, corolla and stamens being attached at practically the same level as the single carpel. The flower is therefore **perigynous** (p. 327).

FIG. 259.—Section of flower of Garden Pea. (After Oliver.)

The **calyx** is gamosepalous, 2-lipped or 5-toothed; in the latter case (the commoner condition) the odd lobe is anterior (at the front). The **corolla** (Fig. 261, *6*) is polypetalous; the large odd petal, called the "standard," is posterior (at the back); the two side petals are called the "wings"; the two anterior petals are locked together to form the boat-shaped "keel" which encloses the stamens and carpel. There are ten **stamens**—in some species all united by the lower halves of their filaments (monadelphous)* to form a tube surrounding the carpel

* Forming "one brotherhood" (Greek, *adelphos*, brother).

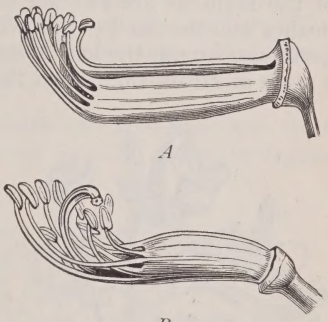
(Fig. 260, *B*), but in most species having the upper (back) stamen free, while the other nine filaments are united (diadelphous) * to form a trough containing nectar (Fig. 260, *A*). **Gynaecium**, one carpel, superior. Placentation marginal.

The nectar-producing species, with diadelphous stamens, are herbaceous, and have a five-toothed calyx. The species with monadelphous stamens include broom, laburnum, lupin, petty whin, gorse, and rest-harrow. Most of these are of shrubby habit, and all except rest-harrow have a two-lipped calyx; they are visited by insects for the sake of pollen only, since they do not produce nectar.

Typical floral formulae are:

Pea, $K_{(5)}C_5A_{(9)+1}\underline{G_1}$;

Gorse, $K_{(2)}C_5A_{(10)}\underline{G_1}$.



A

B

FIG. 260.—*A*, diadelphous stamens of Pea. *B*, monadelphous stamens of Broom. (Enlarged.) (After Oliver.)

Pollination.—The Leguminosae show several interesting adaptations for cross-pollination by insects. As both pollen and nectar (when present) are concealed in the keel, they can be obtained only by fairly strong and intelligent insects, and in many cases (*e.g.* red clover) the nectar can only be reached by a rather long proboscis. Bees (especially humble bees) are therefore the chief agents of cross-pollination (p. 344). The insect, attracted chiefly by the conspicuous standard, alights upon the wings, and—since the wings and keel are locked together—its weight depresses both wings and keel; both the stigma and the anthers are forced out and rub on the lower surface of the insect's body. This, presumably, is already dusted with pollen (from similar flowers previously visited), some of which sticks to the stigma, and the insect flies off with a new supply of pollen which will similarly serve for pollinating flowers visited later. In such cases pollen from the same flower also must often reach the stigma, but such pollen has generally no effect (p. 339) in Leguminosae. When the weight of the insect is removed, the keel rises to its former position, concealing and protecting the essential organs as before.

* Forming "two brotherhoods."

The process just described is the simplest mode of cross-pollination found in Leguminosae; it occurs in laburnum, clovers and melilot. In the garden pea, sweet pea, and vetches, the stamens remain inside the keel, but the pollen they have previously shed is swept out on to the bee's body (by a brush of hairs on the emerging style) as the keel is depressed. In spite of this, self-fertilisation in annual peas is usual (p. 347). In rest-harrow, bird's-foot trefoil, and lupine the filaments of five of the stamens are swollen and form a piston which similarly pushes out the shed pollen when the keel is depressed. In the gorse and broom the keel is small, and holds its contents in such a state of strain that when the keel is pressed down by a bee it tears open, and the style and stamens spring out suddenly, hitting the insect; the stigma thus receives pollen from a previously-visited flower, whilst new pollen is scattered over the bee's body.

FIG. 261.—Bird's-foot Trefoil. 1, flowering branch ($\times \frac{2}{3}$); 2, flower; 3, pistil and stamens; 4, pistil ($\times 1\frac{1}{3}$); 5, fruit ($\times \frac{2}{3}$); 6, corolla: *a*, standard; *b*, wings; *c*, keel; 7, diagram of flower. (After Strasburger.)

The method of **dispersal** of the ripe seeds has been described on p. 364.

The **leaves** of Leguminosae are often specially interesting. They are alternate and stipulate, usually pinnate and compound (even gorse has ternate leaves in the seedling stage), and in many species have one or more leaflets modified to form tendrils (pp. 59 and 188), the reduction of leaf blade being compensated for by enlargement of the stipules, and sometimes (p. 189) by flattening of the leaf stalk and stem. The leaflets are often capable of separate movement by means of swellings (*pulvini*) at the bases of their stalks (*e.g. Robinia* (Fig. 44), clover, p. 257), a power found highly developed in the bipinnate leaves of *Mimosa* (the sensitive plant, p. 258) which belongs to a group of Leguminosae not represented among native British plants.

The **roots** of Leguminosae are peculiar in bearing nodules containing bacteria capable of working up atmospheric nitrogen into compounds which plants can use for food-making (p. 234).

FAMILY ROSACEAE.

Plants recommended for study.—Sloe, cherry, plum, apricot, etc. (*Prunus spp.**, March-June), cinquefoil, silverweed, tormentil (*Potentilla spp.*, June-Sept.), strawberry (*Fragaria*, May-July), blackberry or bramble (*Rubus*, July-Sept.), avens (*Geum*, June-Aug.), wild rose (*Rosa*, June, July), agrimony (*Agrimonia*, June, July); apple, pear, quince, rowan, service, medlar, white beam (*Pyrus spp.*, March-June): hawthorn (*Cratægus*, May, June).

Distinguishing features.—The plants are dicotyledonous trees, shrubs or herbs, with *stipulate* and usually alternate leaves. Almost all kinds of **inflorescence** occur. The **flowers** are regular, perigynous to epigynous, with 4 or 5 sepals, the same number of petals, stamens indefinite, carpels usually indefinite, apocarpous in bud but sometimes becoming more or less syncarpous later.

Fig. 262.—Blackberry. 1, flowering branch (× ½); 2, longitudinal section of flower (× 1); 3, fruit (× ½); 4, diagram of flower.

All stages may be seen, from the slight perigyny of meadow-sweet and cinquefoils (in which the thalamus flattens below the carpels to form a disc, to the edge of which calyx, corolla and stamens are attached), and the marked perigyny of the cherry and agrimony (with a cup-shaped thalamus) and rose (with an urn-shaped thalamus), to the virtual epigyny of the apple. Nectar is usually formed on the thalamus between the carpels and the stamens, which are introrse. The fruits vary widely, as will be seen below.

* Means "various species of the genus *Prunus*."

British Rosaceae fall more or less distinctly into the following groups:

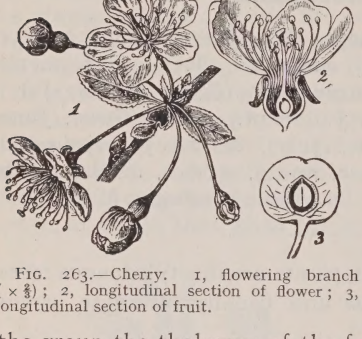


FIG. 263.—Cherry. 1, flowering branch ($\times \frac{2}{3}$); 2, longitudinal section of flower; 3, longitudinal section of fruit.

(1) Cinquefoil, strawberry, blackberry, etc.—The thalamus is a disc or shallow saucer with a central swelling or knob carrying the separate carpels on the outside. In the strawberry the knob of the thalamus becomes succulent. In *Rubus* (blackberry (Fig. 262), raspberry, dewberry, etc.), the thalamus becomes dry but the carpels are fleshy (drupelets) when ripe. In most other plants of the group the thalamus of the fruit is dry and the carpels form achenes, hooked in avens (*Geum*, Fig. 225). *Spiraea* (meadow sweet) has 3-12 follicles. The calyx has often extra sepals (epicalyx).

The great general resemblance of this group to Ranunculaceae should be noticed. It is sharply distinguished by the leaves, and by having perigynous instead of hypogynous flowers, the difference being very obvious in longitudinal sections. Also the stamens are whorled, not spiral (cf. Figs. 199 and 266). The typical floral formula is: $K_{(5)}C_5A_{5+5+5+\ldots}G_{\infty}$.

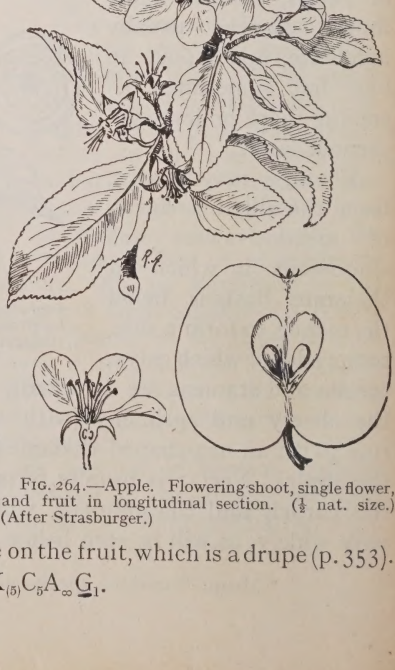


FIG. 264.—Apple. Flowering shoot, single flower, and fruit in longitudinal section. ($\frac{1}{2}$ nat. size.) (After Strasburger.)

(2) Cherry, plum, sloe, almond, apricot.—The plants are various species of the genus *Prunus* (Fig. 263). The thalamus is cup-shaped. There is only one carpel, the position of the fused margins being marked by a groove on the fruit, which is a drupe (p. 353).

Floral formula: $K_{(5)}C_5A_{\infty}\underline{G}_1$.

(3) Agrimony, rose, etc.—The thalamus is more or less deeply cup-shaped, with separate carpels attached to its inner surface. The floral formula of the rose is as in Group 1; the ripe fruit is a red, fleshy "hip" (Fig. 230). Agrimony has only 1 or 2 carpels; its epicalyx is bristly and hooked (p. 234, *A*). Lady's mantle has no petals; it has 4 sepals with an epicalyx, only 4 stamens, and 1 or 2 carpels. Salad burnet has no petals; the inflorescence is a globular head, the lower flowers being male with dangling stamens, the upper flowers female with branched stigmas on the 1-3 carpels, which form achenes; pollination is by the wind.

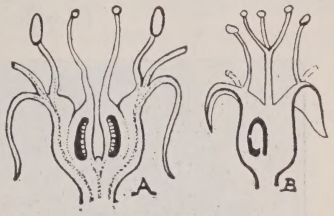


FIG. 265.—*A*. Longitudinal section of Quince blossom, showing an apparently inferior ovary, but the styles and stigmas are separate. *B*. Longitudinal section of Apple blossom, showing styles united, but stigmas still separate. (After Warming.)

(4) Apple, pear, rowan, quince, white beam, service, medlar (all belonging to the genus *Pyrus*), and **hawthorn.**—The flower is epigynous,

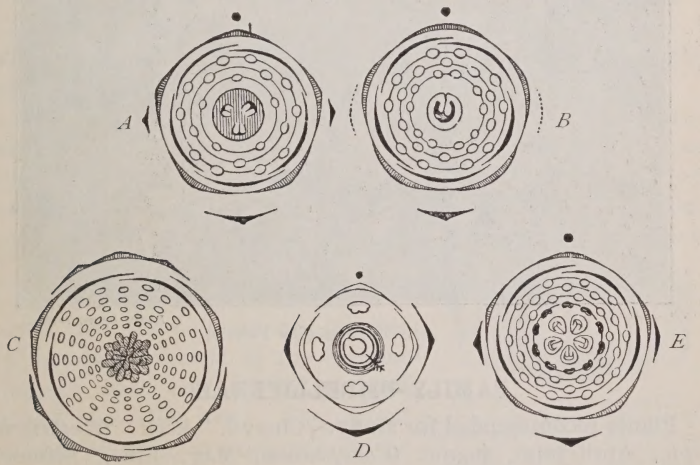


FIG. 266.—Floral diagrams of Rosaceae. *A*, Service-tree; *B*, Bird cherry; *C*, Rose; *D*, Great Burnet; *E*, Meadow-sweet (*Spiraea*). (After Eichler.)

since the thalamus has grown round and enclosed the ovaries (Fig. 265). By ingrowth of the thalamus between them the ovaries are united (pseudo-syncarpous), their walls being horny

in *Pyrus* and woody in the hawthorn. The thalamus of the ripe fruit is fleshy.

Floral formulae: *Pyrus* (*e.g.* Apple), $K_{(5)}C_5A_\infty\underline{\bar{G}_{(5)}}$;
Hawthorn, $K_{(5)}C_5A_\infty\underline{\bar{G}_{1-2}}$.

Photo. Henry Irving.

FIG. 267.—Hogweed (Cow Parsnip).

FAMILY UMBELLIFERAE.

Plants recommended for study.—Chervil, " keck " (*Anthriscus spp.*, April-July), pignut (*Conopodium*, May, June), hemlock (*Conium*, June, July), hogweed (*Heracleum*, July, Aug.), carrot (*Daucus*, June-Aug.), hedge parsley (*Caucalis*, Aug., Sept.), etc.

Distinguishing features.—Dicotyledonous herbs; stem erect, often ribbed, with hollow internodes; **leaves** alternate, pinnate,

with broad sheathing leaf-base; **inflorescence** usually a *compound umbel* (p. 311); **flowers** small, polypetalous, usually white or yellow, **epigynous**; the inferior ovary has 2 chambers with one ovule in each, and is covered by a disc (nectary), on the edge of

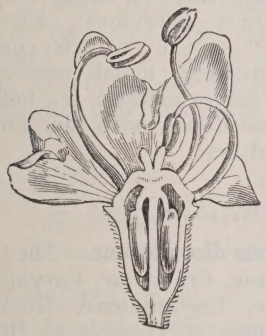


Fig. 268.—Single flower of Hogweed (Cow Parsnip) cut in half longitudinally. (× 5.) (After Oliver.)

Fig. 269.—Hogweed. A half-fruit (mericarp) seen from the outer side, showing four vittae. (× 4.) (After Oliver.)

which are inserted the toothed or inconspicuous sepals, the petals and stamens, all separate.

The flowers, though small, are rendered collectively conspicuous by being grouped in umbels. They are mostly protandrous and chiefly cross-pollinated by flies, to which the nectar produced on the surface of the disk is easily accessible. The anterior petals of the outer flowers of each group are often enlarged. [Compare candytuft (p. 378) and Compositae (p. 402)]. Failing cross-pollination, self-pollination is possible by bending inwards of the introrse stamens after the two styles have turned back (Fig. 268). The virtual absence of sepals is explained by the close growth of the small flowers and by the protective bracts [compare Compositae]. The ripe fruit splits into 2, usually dangling, achenes, the pericarp being ridged and generally traversed by oil canals called *vittae* (Figs. 269 and 270). Other parts of the plant also commonly contain aromatic

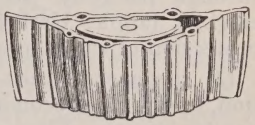


Fig. 270.—Transverse section of mericarp of Hogweed, showing the ridges and vittae of the pericarp, also the embryo surrounded by endosperm. (× 7.) (After Oliver.)

oils; some of these are used for flavouring, *e.g.* parsley leaves, carraway seeds, angelica stem.

Common British Umbelliferae are hemlock (very poisonous, recognisable by its smooth spotted stem), cow parsnip (hogweed), carrot (has prickly carpels), hedge parsley, fool's parsley (very poisonous), angelica, earth nut, wood sanicle (carpels covered with hooked prickles), marsh pennywort (stem prostrate, leaves peltate), sea holly (a xerophyte of sand dunes, with blue flowers in a cymose head), etc.

FIG. 271.—Floral diagram of Umbelliferae.

Floral formula :

$$\overline{K_5C_5A_5G_{(2)}}.$$

The polypetalous dicotyledons.—The families Ranunculaceae, Cruciferae, Caryophyllaceae, Violaceae, Leguminosae, Rosaceae and Umbelliferae—selected from some 50 families of British dicotyledons with separate petals—illustrate certain stages in the "improvement" of flower-structure in various respects, by which, in the course of ages, seed production has been rendered more and more efficient. The earliest flowers must have resembled the simplest flowers of modern Ranunculaceae more than they resembled the flowers of any of the other families we have studied, and it will be interesting to consider some advantages which have been gained by the various departures from this ancient type.

(1) The change from hypogyny (still found in Ranunculaceae, Cruciferae, Caryophyllaceae, Violaceae and many other families), through perigyny (seen in Leguminosae, Rosaceae, etc.) to epigyny (apple, Umbelliferae, etc.) plainly makes for greater protection of the ovules and developing seeds.

(2) In general, cross-fertilisation is better than self-fertilisation, and is most economically secured (p. 344) by cross-pollination by insects. Flowers which show the most perfect adaptation to insect pollination—especially zygomorphic flowers (*e.g.* monkshood, larkspur, Violaceae, Leguminosae,)—are therefore, other things being equal, to be considered the most advanced. Again, a closely-massed inflorescence of small flowers is more economical, and may be more successful, than the same number of large, separate flowers. Flowers which, in any of these ways, are able to secure the visits of suitable insects, can safely economise by having fewer stamens and carpels, and by

fusion of the latter—features which indicate a higher stage of evolution.

From both points of view it is clear that one or two seeds, well protected, nourished and dispersed (as in Umbelliferae, etc.), are more likely in this particular respect to continue the race than a larger number which are less perfectly equipped (as in certain Ranunculaceae, etc.). It will be readily understood, however, that a plant's chance of survival also depends on many other circumstances, some of which may be of more importance than any particular refinement of floral efficiency.

47. SOME FAMILIES OF GAMOPETALOUS DICOTYLEDONS.

We shall next study a few families of Dicotyledons which have the petals fused to form *corolla-tubes* of various lengths, a feature which renders cross-pollination more certain, because it makes the nectar inaccessible except to the longer-tongued insects and by a narrowed path in which anthers and stigma are placed. The same result, it will be remembered, is secured, though less perfectly, by the long, narrow "claws" of the petals (held together by the calyx) of Cruciferae and the silenoid Caryophyllaceae. In most cases when the corolla is gamopetalous, the stamens are attached to the corolla (epipetalous); this plainly allows of a narrower corolla-tube.

FAMILY PRIMULACEAE.

Plants recommended for study.—Primrose (*Primula vulgaris*, March-May), cowslip (*P. veris*, May, June), water violet (*Hottonia*, May-July), pimpernel (*Anagallis*, June-Nov.), loosestrife, moneywort (*Lysimachia spp.*, May-Aug.), brookweed (*Samolus*, June-Sept.).

Distinguishing features.—Dicotyledonous herbs. **Flower** regular; **Calyx** gamosepalous, inferior; **Corolla** gamopetalous, hypogynous. **Stamens** epipetalous and *opposite the corolla lobes.* **Ovary** superior, one-chambered, placentation completely free-central, stigma knob-like. The number of carpels is indicated

by the 5 teeth by which the ripe **fruit** (a capsule) of most Primulaceae opens when ripe; the scarlet pimpernel fruit, however, opens by a lid (Fig. 273).

Floral formula: $K_{(5)}\widehat{C_{(5)}A_5}\underline{G_{(5)}}$.

Heterostylic Primulaceae.—Primrose, cowslip, oxlip and "water violet" are native, but introduced species of *Primula*, *Auricula* and *Polyanthus* are also well known. In this group the corolla-tube is long and narrow, and the nectar at the bottom can only be reached by long-tongued insects. Insects small enough to pass bodily down the tube are too weak to push aside the anthers which block the passage, while the hairy, ridged calyx-tube saves the corolla-tube from being bitten through from outside. Each species in this group produces two kinds of flowers, which grow on separate plants. In what is called a "pin-eyed" primrose (Fig. 272, *B*) the style is long, and the stigma—looking somewhat like the head of a pin—is at the top of the corolla-tube, while the anthers are half-way down. The short-styled or "thrum-eyed" form of primrose (*A*) has the anthers at the top, while the stigma is halfway down the tube, exactly opposite the place where, in the pin-eyed form, the stamens are situated. The primrose and other plants of this group of Primulaceae are said to be heterostylic,* because in the same species flowers occur having different lengths of style.

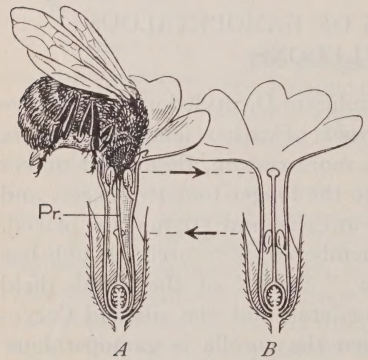


FIG. 272.—Pollination of Primrose. *A*, thrum-eyed; *B*, pin-eyed form; *Pr*, proboscis. For explanation, see text.

Cross-pollination.—A humble bee, thrusting its proboscis down a thrum-eyed primrose in search of the nectar at the bottom (Fig. 272, *A*), dusts itself with pollen just in the place which will come in contact with the stigma when the insect visits a pin-eyed flower. And the pollen from the pin-eyed form adheres to the part of the bee's proboscis which will presently touch the stigma of a short-styled flower. This beautiful and simple arrangement makes cross-pollination highly probable. In the thrum-eyed

* Greek, *heteros*, different.

form, however, self-pollination is possible by pollen falling on the stigma, and may occur in pin-eyed flowers, which in the later stages hang upside-down. Pollen from the same flower must also occasionally be placed on the stigma during the insertion or withdrawal of the insect's proboscis. Charles Darwin proved that the seeds produced by crossing the two forms are more abundant and more vigorous than those formed by crossing two flowers of the same kind, but that even the latter seeds are better than those resulting from self-fertilisation.

Fig. 273.—Scarlet Pimpernel (½ nat. size). Longitudinal section of flower and capsule at dehiscence (enlarged). (After Strasburger.)

Other Primulaceae.—Scarlet pimpernel (Fig. 273), yellow loosestrife and creeping Jenny (moneywort, Fig. 273A) differ from the heterostylic Primulaceae in having their petals joined only at the base, so that the corolla is

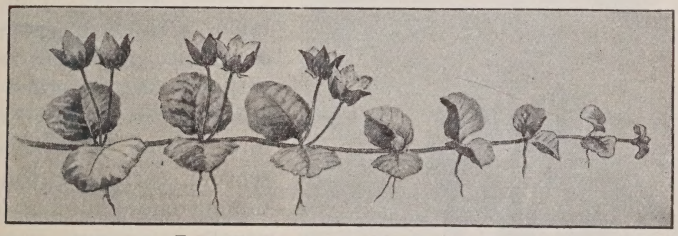


Fig. 273A.—Moneywort (Creeping Jenny).

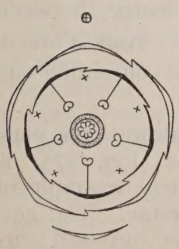


Fig. 274.—Floral diagram of Primulaceae.

not tubular, and the nectar can be reached by short-tongued insects. Brookweed, a marsh plant, is specially interesting because it has five imperfect stamens (staminodes) opposite the calyx-lobes, in addition to the five opposite the corolla-lobes. Evidently the ancestors of the other Primulaceae also had 10 stamens: an outer five (now lost) opposite the sepals, and an inner five opposite the petals. The lost stamens are indicated by small crosses in Fig. 274.

FAMILY LABIATAE.

Plants recommended for study.—Dead-nettles (*Lamium spp.*, Apl.-Nov.), sage (*Salvia*, June-Sept.), ground ivy (*Nepeta*, March-May), skull-cap (*Scutellaria*, July-Sept.), self-heal (*Prunella*, July-Sept.), hemp-nettle (*Galeopsis*, July-Sept.), wood sage (*Teucrium*, July-Sept.), bugle (*Ajuga*, May-July).

Distinguishing features.—Dicotyledonous herbs or small shrubs with square stems and opposite, decussate, simple, usually hairy, leaves. **Inflorescence** usually an axillary group of short-stalked or sessile flowers, the oldest in the middle. **Flowers** gamopetalous, irregular (zygomorphic); **calyx**, polysepalous; **corolla**, two-lipped, hypogynous; **stamens**, epipetalous, 4, rarely 2; **gynaecium**, bicarpellary, syncarpous; *stigma* forked; *ovary* superior, divided into 4 lobes by a false septum, each lobe containing one ovule; *style* usually springing from base of ovary, between the lobes. **Fruit**, 4 lobed, each lobe containing one seed.

Photo. Henry Irving.

FIG. 275.—White Dead-nettle.

Pollination.—**The white dead-nettle** (Fig. 275) is an excellent example of the Labiatae. The corolla faces outward; its upper (back) lip forms a hood protecting the anthers and stigma,

its lower (front) lip (Fig. 276, *Ca*) a landing-stage for bees. The position occupied by the style perhaps accounts for the absence of the back stamen. The arrangement leaves the cavity and the front wall of the corolla-tube free for bees visiting the flower for nectar ; this is secreted by a disk (*n*) which surrounds the base of the ovary, but is especially large on its front side. Standing on the lower lip and pressing into the corolla-tube, a humble bee can reach the nectar with its proboscis. As the bee enters the flower, its hairy back touches the stigma (*sg*), which, when ready for pollination, is a little *in front of and below* the anthers. The lower fork of the stigma is thus pressed down and probably receives pollen (already present on the bee's back) on its stigmatic (inner) surface. The anthers next come in contact with the bee's body, and their pollen is brushed off by its hairs. This is not likely to reach the stigmatic surface of the same flower, however, for the contact of the bee withdrawing from the flower naturally presses the lower lobe of the stigma against the upper lobe. A ring of hairs (*h*) near the bottom of the corolla-tube prevents small insects from crawling down to the nectar.

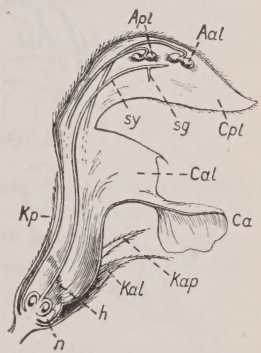


FIG. 276.—Flower of White Dead-nettle cut in half longitudinally. *Kp*, *Kal*, *Kap*, sepals (posterior, posterior lateral and anterior lateral) ; *Ca*, *Cal*, *Cpl*, petals (anterior, anterior lateral and posterior lateral) ; *Aal*, *Apl*, stamens (anterior lateral and posterior lateral) ; *sg*, stigma ; *sy*, style ; *h*, ring of hairs ; *n*, nectary. Compare with Fig. 278.

In the white dead-nettle, the anthers and stigma are mature together, but most Labiatae are protandrous, the anthers and stigma occupying *in turn* the same position in the flower as they become mature. The result is that insect visitors leave pollen from younger flowers on the stigma.

The mechanism of cross-pollination is particularly interesting in **Sage** (Fig. 277). Two of the four stamens are imperfect (staminodes). Each of the other two stamens is much modified, having somewhat the shape of a capital T, the short upright (*f*) being the filament, while the crosspiece (*m*) is the connective, at each end of which is a pollen lobe or half-anther (*a*, *a'*). Usually the connective is not at right angles to the filament, but is swung up—the junction acts as a hinge—until it is nearly vertical (Fig. 277, *D*). The pollen lobe *a*, which is at the lower end of the connective *m*, when this is vertical, contains hardly any pollen in

the garden sage, but is fertile like the upper one (*a'*) in wild sage. The entrance to the corolla-tube is thus guarded by two pillars, the filaments (*f*) of the stamens; and the lower pollen-lobe, at

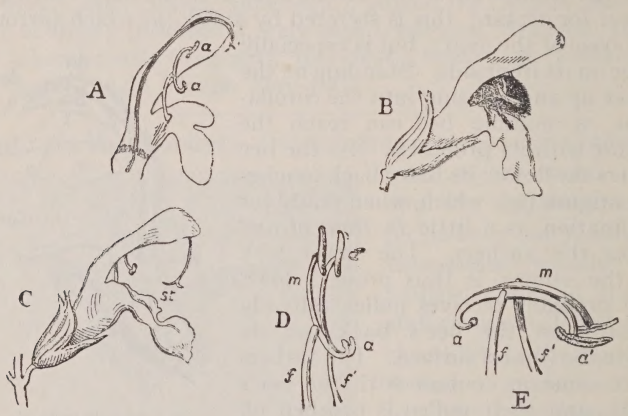


FIG. 277.—Garden Sage. *A*, section of young flower; *B*, flower visited by a bee; *C*, older flower; *D*, stamens in natural position; *E*, stamens when moved by a bee. All enlarged. *a*, sterile, *a'*, fertile half of anther; *f*, filament; *m*, connective; *st*, stigma. (After Avebury.)

the bottom of the upright connective of each stamen, is directly in front of the bee's head as it stands on the lower lip of the flower. When the bee pushes forward its head to reach the nectar it comes in contact with the lower pollen lobes, and the top-heavy connectives swing round on their hinges, so that the upper pollen lobes strike the bee's back and dust it liberally with pollen. Having shed their pollen, the stamens shrivel up, and the pistil comes to maturity. As the pistil ripens, the stigma arches over (Fig. 277, *C*) so as to scrape along the back of any bee visiting the flower for nectar, and thus to wipe off the pollen which has been brought from a younger flower.

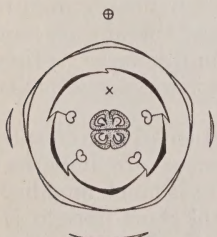


FIG. 278.—Floral diagram of Labiatae.

Although most of the British plants of this family are adapted to cross-pollination by bees, some (*e.g.* thyme, mints, marjoram, etc.) have shallow and almost regular flowers which are pollinated casually by various small insects. Ground ivy, mint, thyme, marjoram and self-heal have not only hermaphrodite but

also unisexual flowers. Many Labiatae are aromatic, having on their leaves glandular hairs which secrete volatile oils valued for flavouring food, etc. Sage, mint, thyme, marjoram, lavender and rosemary are well known examples. No labiate is poisonous.

Floral formula, typically, - $K_{(5)}\widehat{C_{(5)}A_4}\underline{G_{(2)}}$

Sage, rosemary and gipsywort, $K_{(5)}\widehat{C_{(5)}A_2}\underline{G_{(2)}}$.

FAMILY SCROPHULARIACEAE.

Plants recommended for study.—Foxglove (*Digitalis,* June-Aug.), mullein (*Verbascum,* June-Nov.), toadflax (*Linaria,* July-Nov.), snap-dragon (*Antirrhinum,* July-Nov.), figworts (*Scrophularia spp.,* Apl.-June and July-Sept.), speedwells (*Veronica spp.,* March-Oct.).

Distinguishing features.—Dicotyledonous herbs or shrubs; **flowers** gamopetalous, hypogynous, more or less zygomorphic and 2-lipped. **Stamens** usually four (sometimes 2 or 5), epipetalous; **ovary** superior, 2-chambered with numerous ovules on an axile, swollen placenta. **Fruit** a capsule. The family is distinguished from the Labiatae chiefly by the characters of the ovary and fruit.

Pollination.—All the Scrophulariaceae are adapted to cross-pollination by insects. The flowers of most are very irregular, 2-lipped and protandrous, and cross-pollination is made probable by anthers and stigma occupying in succession a position which brings them in contact with the same region (usually the back) of an insect reaching for the nectar formed round the base of the ovary. Certain pollination mechanisms are specially interesting.

The *foxglove* corolla (Fig. 279) is tubular ("glove-shaped") and hangs obliquely downward. The bee walks up the hairy, spotted "floor," and its back brushes against the ripe stigma or anthers (according to the stage of development), under the "roof." In *snap-dragon* (Fig. 280) and *toadflax* (Figs. 195 and 281) the upper and lower lips of the corolla are in contact, so that the entrance to the tube is closed, and can be opened only by strong

insects. The toadflax corolla is prolonged into a spur (*sp*) in which the nectar collects; in snap-dragon a slight pouch takes the place of the spur. Bees often bite through both

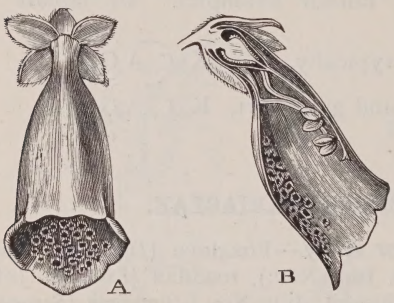


FIG. 279.—Flower of Foxglove. *A*, seen from the front; *B*, cut in half longitudinally. (After v. Wettstein). For habit of plant, see Fig. 161.

FIG. 280.—External appearance of flower of Snap-dragon. (After Figuier.)

to get the nectar from outside. The stigma of the *musk* is irritable, its two flaps remaining separated when untouched, but closing together promptly and remaining closed for some little time when touched (and probably cross-pollinated) by a bee entering the flower. Self-pollination by the bee as it leaves the flower is thus prevented. The *figwort* is exceptional in being protogynous (*i.e.* the stigma matures before the anthers), and stigma and anthers in turn occupy a position close to the *lower* lip, and therefore come in contact with the *under* surface of the insects (in this case mostly wasps) visiting the flower. In this flower there is more room than usual for the back stamen—usually absent in Scrophulariaceae as in Labiatae (p. 397)—but, being useless here, it is only represented by an abortive stamen (staminode).

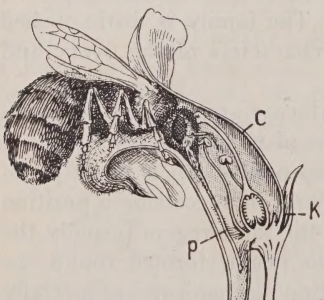


FIG. 281.—Pollination of Toadflax. *K*, posterior sepal; *C*, corolla-tube; *sp*, spur; *p*, proboscis of bee. See also Fig. 195.

In the *mulleins* (Fig. 282), the flower is almost regular, with expanded petals and a very shallow corolla-tube. All five stamens are present and fully developed; they spread outwards, but the style bends downwards, so that

the bilobed stigma hangs over the anterior petal. The ancestor from which all the modern Scrophulariaceae are descended must have had a flower somewhat like that of the present-day mullein.

The speedwells and other *Veronicas* have also shallow flowers, but are much modified from the normal type of the family.

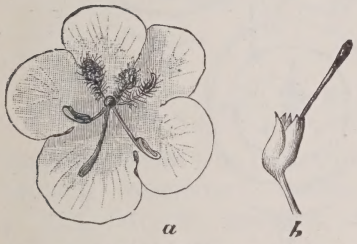


FIG. 282.—Mullein (*Verbascum thapsiforme*). *a*, flower; *b*, calyx and style (nat. size). (After Strasburger.)

FIG. 283.—Germander Speedwell (*Veronica Chamaedrys*).

They have only four sepals, the back sepal having disappeared; four lobes to the corolla, the large back lobe being probably equivalent to two; and two stamens. The style lies over the lower petal and between the two stamens. Hover flies alighting on the flower reach *over* and touch the projecting stigma in their search for nectar, pulling forward the two stamens (which they grasp for support) so that the anthers also rub on the lower part of their bodies. The genus *Veronica* shows a great range of vegetative variation. British species are small herbs, but other well-known species are shrubs with thick xerophytic leaves.

The floral diagrams of typical Scrophulariaceae, mullein and speedwell should be compared carefully with each other and with those of Labiatae.

Floral formulae: usually, $K_{(5)}\widehat{C_{(5)}A_4}\underline{G_{(2)}}$;

Mullein, $K_{(5)}\widehat{C_{(5)}A_5}\underline{G_{(2)}}$;

Veronica, $K_{(4)}\widehat{C_{(4)}A_2}\underline{G_{(2)}}$.

The family includes a number of semi-parasites which prey on the roots of grasses (p. 228). Among them are eye-bright,

red rattle, yellow rattle, cow-wheat and lousewort. Toothwort is parasitic on the roots of trees.

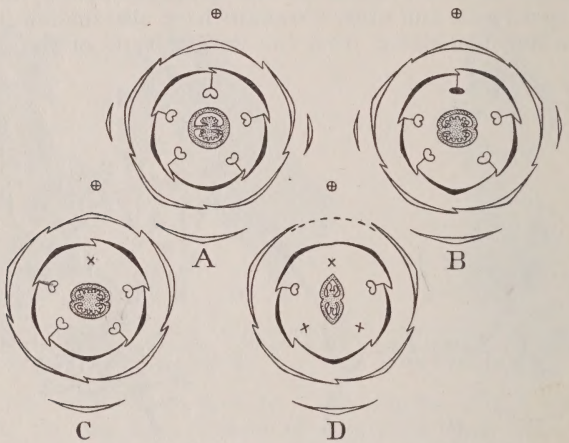


FIG. 284.—Floral diagrams of Scrophulariaceae. *A*, Mullein; *B*, Figwort; *C*, Foxglove, Snapdragon, Toadflax, etc.; *D*, Veronicas. Missing stamens are indicated by small crosses.

Certain Scrophulariaceae are poisonous, the foxglove being especially so in all its parts.

FAMILY COMPOSITAE.

Plants recommended for study.—Dandelion (*Taraxacum*, March-Aug.), hawkweeds (*Hieracium spp.*, June-Sept.), goatsbeard (*Tragopogon*, June, July), sowthistle (*Sonchus*, June-Aug.), chicory (*Cichorium*, July-Oct.), knapweeds, cornflower (*Centaurea spp.*, June-Sept.), burdock (*Arctium*, July, Aug.), thistles (*spp.* of *Cnicus* or *Carduus*, June-Sept.), daisy (*Bellis*, Feb.-Nov.), corn-marigold, ox-eye daisy, feverfew (*Chrysanthemum spp.*, July-Sept.), Michaelmas daisy (*Aster*, Aug.-Oct.), ragwort and groundsel (*Senecio spp.*, June-Sept. and April-Dec.), yarrow (*Achillea*, July-Oct.), sunflower (*Helianthus*, gardens, summer), coltsfoot (*Tussilago*, Feb.-May), butterbur (*Petasites*, March-May).

Distinguishing features.—British species are all herbaceous. **Inflorescence** a head (capitulum, p. 492) of small **flowers** (florets)

on a broad receptacle which is surrounded by whorls of bracts called the involucre.* **Calyx** sometimes absent, but in most cases represented by an epigynous tuft of hairs

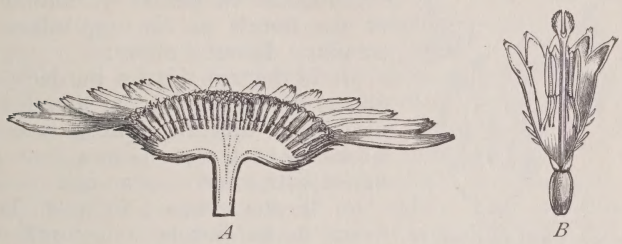


FIG. 285.—Daisy. *A*, section of capitulum. (× 3.) (After Figuier.) *B*, a disc floret with the corolla tube laid open (× 15). (After Avebury.)

(pappus); **corolla** 5 or 3, gamopetalous, tubular or strap-shaped (ligulate), epigynous; **stamens** 5, epipetalous, syngenesious (p. 332), introrse; **gynoecium**, *stigma* bilobed; *ovary* inferior, with only 1 chamber and containing 1 ovule, although the pistil was originally bicarpellary, as shown by the forked stigma. **Fruit** an achene, in most cases dispersed by a pappus (p. 362).

FIG. 286.—Dandelion. 1, two heads and a leaf (× ⅔); 2, a single flower (× 2); 3, fruit (× 3); 4, receptacle, with one fruit. (After Strasburger.)

Sub-family Liguliflorae.—In dandelion, hawkweeds, chicory, goat's beard (John-go-to-bed-at-noon), sowthistle, lettuce, etc., *all* the florets of the capitulum are ligulate, having the corolla prolonged on the outer (front) side to form a strap ending with 5 teeth, indicating 5 petals; the lower part only of the corolla forms a short tube to which the stamens are attached (Fig. 286, *2*). All the florets are hermaphrodite (*i.e.* have both stamens and ovary). A

* In some cases (*e.g.* sunflower, cat's-ear, May-weed) each floret also has a bract, on the receptacle.

milky white juice called *latex* exudes when any part of the plant is cut or broken, and stiffens on contact with air, thus sealing up the wound.

FIG. 287.—Vertical section of capitulum of Corn Centaurea, one neuter ray-floret and one hermaphrodite disc-floret being left. (After Oliver.)

Sub-family Tubuliflorae.—Some or all of the florets of the capitulum are tubular. Latex is absent.

(*a*) In the true thistles, burdock, etc., all the florets are tubular and hermaphrodite. Creeping thistle is exceptional in that some plants bear only florets with abortive stamens.

(*b*) In the genus *Centaurea* (knapweeds or hardheads, and cornflower), all the florets are tubular; but while the more central, or disc florets, are hermaphrodite, those near the edge of the capitulum (ray florets) are neuter, and, being of large size, serve only to attract the attention of insects (Fig. 287).

FIG. 288.—Feverfew, with enlarged ray and disc florets and fruit.

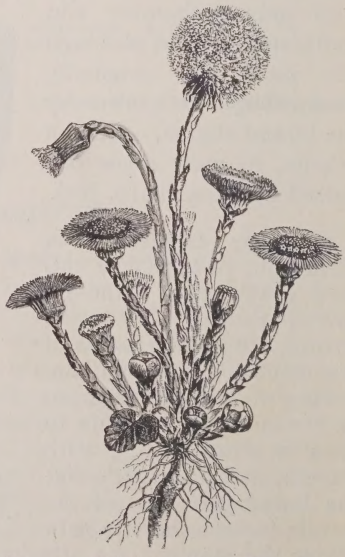


FIG. 289.—Coltsfoot. (After Strasburger.)

(*c*) In a large number of Compositae, only the disc florets are tubular; the ray florets are ligulate, with 3 teeth, often

differently coloured and very conspicuous. In most plants of this group—*e.g.* the field daisy (*Bellis*), ox-eye or dog daisy, feverfew (*Chrysanthemum spp.*), Michaelmas daisy (*Aster*), chamomile, ragwort and milfoil or yarrow, etc.—the tubular disc florets are hermaphrodite (Fig. 285, *B*), while the ligulate ray florets are female, having no stamens. In the sunflower, the ray florets are neuter, the disc florets hermaphrodite. Groundsel is of the same genus (*Senecio*) as ragwort, but has lost its ray florets; its disc florets are usually self-pollinated (p. 347). Some tropical *Senecios* are shrubs. In garden marigold and coltsfoot, the tubular disc florets are male only, the ligulate ray florets female only. Butterbur is closely related to coltsfoot, but has only disc florets; usually these are of one sex only, all the florets being female in the capitula of some plants, and all male in those of others.

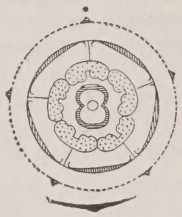


Fig. 290.—Floral diagram of Compositae (*Carduus*). (After Strasburger.)

Typical floral formulae:

Dandelion, $K_{pappus}\overset{\frown}{C_{(5)}}A_{(5)}\overline{G_{(2)}}$;

Daisy—Ray fl., $K_0C_{(3)}A_0\overline{G_{(2)}}$; Disc fl., $K_0\overset{\frown}{C_{(5)}}A_{(5)}\overline{G_{(2)}}$.

Pollination.—In the florets of most Compositae the nectar is abundant and accessible to all sorts of insects, which creep leisurely about the capitulum and carry pollen from floret to floret. The nectar of knapweeds and thistles, which have long corolla-tubes, is beyond the reach of short-tongued insects, and these plants are visited chiefly by humble bees and butterflies (p. 344). Throughout the family, the hermaphrodite florets are protandrous, all **stages of development** (Fig. 291) being visible in the same capitulum. (i) In the middle of the disc the young florets may be still small and closed. (ii) Surrounding these are opened florets, each with a little heap of pollen to be seen inside the ring of united anthers. (iii) Next come older florets, in which the tip of the stigma (its lobes still unseparated) has appeared. As the elongation of the style pushes

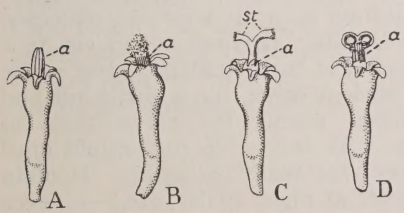


Fig. 291.—Disc florets of Feverfew, showing stages of opening. *a*, stamens; *st*, stigma. (Partly after Avebury.)

the stigma up the anther tube, the shed pollen is swept *gradually* out of the tube by a tuft of hairs on either the stigma or the style.* (iv) In the still older florets nearer the edge of the disc, the stigma, having emerged completely from the ring of anthers, is seen to be forked, exposing the stigmatic surfaces which were formerly face to face. At this stage it is likely to receive pollen from younger florets, carried by insects crawling over the capitulum. (v) Later, the two arms of the stigma curl right back, so that their stigmatic surfaces come in contact with the heap of pollen grains still lying on the top of the anther tube; self-pollination occurs, to be followed by self-fertilisation should cross-pollination fail.

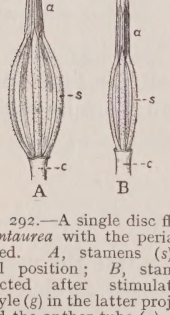


FIG. 292.—A single disc floret of *Centaurea* with the perianth removed. *A*, stamens (*s*) in normal position; *B*, stamens contracted after stimulation. The style (*g*) in the latter projects beyond the anther tube (*a*), and the pollen (*p*) has been brushed out. *c*, lower part of tubular perianth. (After Pfeffer, enlarged.)

A beautiful modification of the "piston mechanism" for sweeping out the pollen, described above, is found in the genus *Centaurea* (knapweeds or hardheads, and cornflower). Here the filaments of the stamens suddenly contract when the tops of the anthers are touched (*e.g.* by an insect), and pull down the anther tube quickly, with the result that the contained pollen is pushed out at the moment when it is most likely to be carried off (Fig. 292).

The involucre.—It should be borne in mind that the receptacle of the capitulum is, as it were, a condensed flower-stalk; it is not equivalent to a thalamus, nor even to a number of fused thalami. Nor is the involucre of bracts in any sense a calyx, for it surrounds and protects the *whole inflorescence* during the early stages of development of the flowers. Its leaves do not unfold until some, at least, of the flowers are ready to open. It often closes again in cold weather or at night (daisy, etc.)—or even at midday in goat's-beard (p. 256)—and also closes during the period of ripening of the seeds (*e.g.* dandelion, etc.).

Seed dispersal.—Each fertilised floret gives rise to one inferior achene (p. 352). In burdock every leaf of the involucre ends

* Even the male flowers of garden marigold, coltsfoot and butterbur have a style to sweep out the pollen, but there is no stigma and the ovary is empty. On the other hand, the stigma and style of female florets are without brush, there being no pollen to sweep out.

in a little hook, and the head of fruits is a "bur" dispersed as a whole by animals (p. 360). In bur marigold, the achenes (Fig. 234, *E*) are dispersed separately by means of the barbed bristles (a modified calyx) surmounting each ovary. Most commonly the calyx is **a pappus of hairs** which acts as a parachute (p. 362) for the achene; but in the daisies, etc., the calyx is practically absent, and these plants have no special means of seed dispersion.

The gamopetalous dicotyledons.—The group of families included for convenience under this heading is an artificial one, for there is good reason to think that the fusion of petals is an "improvement" which many families have adopted quite independently of each other, and therefore it is not a sign of close relationship. The advantage obtained by gamopetaly has been already explained (p. 393). Other things being equal, a gamopetalous corolla indicates a higher grade of development than a polypetalous corolla; and seeing that the Compositae have also the special features of zygomorphy, epigyny, reduction in numbers of essential organs, a closely-massed inflorescence of flowers which show elaborate division of labour—features which (p. 392) combine certainty of efficient fertilisation with great economy of material—and, finally, in most cases, unusually perfect means of dispersion, we are justified in considering the **Compositae the most highly developed of Dicotyledons.** This conclusion is supported by their astonishing success: they flourish in all parts of the world in which flowering plants can live, and the number of their species (upwards of 13,000) is more than ten per cent. of the total number of species of flowering plants.

48. THE OAK AND WILLOW FAMILIES.

FAMILY CUPULIFERAE.

Compare the dates of appearance of flowers and leaves in oak, beech and sweet chestnut. Study the inflorescences, flowers and fruits of common or pedunculate oak (*Quercus pedunculata*, fl. May), sessile oak (*Q. sessilis*, fl. May), beech (*Fagus sylvatica*, fl. May) and sweet chestnut (*Castanea*, fl. July).

Distinguishing features.—Dicotyledonous trees or shrubs. **Leaves** alternate, spiral or two-ranked, simple, with deciduous stipules. The **flowers** do not appear before the leaves (contrast birch family, p. 447), are **monoecious** (contrast Salicaceae, p. 409), unisexual (contrast sycamore, horse chestnut, ash, lime, elms, p. 429), and have a small sepaloid perianth. The *male flowers*, each with 4-12 stamens and sometimes a rudimentary but sterile pistil, are in catkins (p. 311). The *female flowers* are solitary, or 2-3 form a dichasial cyme (p. 313); the carpels, 3-4, have separate stigmas; each loculus of the ovary contains two ovules, but usually only one ovule of each flower develops into a seed, which is without endosperm. **Fruit** nut-like, surrounded by a cupule, which is probably an involucre of bracts. **Pollination** is by the wind.

FIG. 293.—Pedunculate Oak; leaves, flowers and fruit. *A*, flowering branch ($\times \frac{1}{2}$); *B*, a male flower (magnified); *C*, stamens (magnified); *D*, a female flower (magnified); *E*, acorns; *F*, cup of acorn; *G*, *H*, seed. (After Schimper.)

Inflorescence.—In the Cupuliferae, and in the closely-allied birch family (Betulaceae, p. 447), the male flowers usually occur in bracteate *groups* on the axis of the male catkin, each group being a more or less modified dichasial cyme. In the **oak** the male catkins are long, slender, hanging spikes, on which the flowers are arranged in groups or singly; each flower has 5-12 stamens and a perianth with 5-7 spreading lobes. The female catkins contain only 2 or 3 flowers; these are separated on an

elongated peduncle in the pedunculate oak, but form a clustered dichasial cyme in the sessile oak. In the **beech** the male catkin is a dichasial cyme of some 12 flowers, forming a globular cluster at the end of a long, hanging peduncle. Each male flower has about 10 stamens, and a hairy perianth, deeply cleft into 5 or 7 parts. The female catkins are short and erect; each consists of two female flowers with a bracteate cupule surrounding both. The **sweet chestnut** has two kinds of catkins, some bearing male flowers only, and others —nearer the tip of the twig—with numerous male and 2 or 3 female flowers.

FIG. 294.—Beech (¼ nat. size). 1, branch, with male and female inflorescences; 2, male flower; 3, female flower; 4, open cupule with two fruits; 5, fruit; 6, transverse section of fruit, showing folded cotyledons of embryo. (2, 3, enlarged.) (After Strasburger.)

The **vegetative characters** of the oak, beech and sweet chestnut are described on pp. 440 to 447.

FAMILY SALICACEAE.

Distinguishing features.—The only members of the family are the willows (*Salix*) and poplars (*Populus*). They are dicotyledonous trees or shrubs. **Inflorescence** a catkin (p. 311). The plants are **dioecious** (p. 341), each bearing either male flowers only, or female flowers only. Each flower is in the axil of a bract, usually hairy, the margin of which is entire in the willows (Fig. 296), but toothed in the poplars (Fig. 297).

Willows begin to flower early (March and April)—when other flowers are few—and are eagerly frequented by insects, especially bees, for the sake of **nectar**. This is produced in a small disc (nectary) on the axis-side of each flower, which in male willows

consists of from 2 to 5 stamens, according to species, and in female plants is a bicarpellary syncarpous pistil, with bilobed stigma, and a one-chambered ovary with numerous ovules on two parietal

FIG. 295.—Catkins of Willow. *A*, male; *B*, female. (After Figuier.)

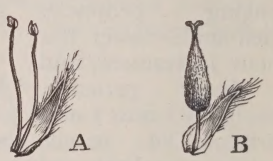


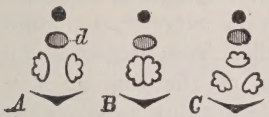
FIG. 296.—Flowers of Willow (*Salix alba*). *A*, male; *B*, female: in each case the subtending bract is also shown. (After Figuier.)

placentas. The **catkins** are erect, the male catkins being rendered conspicuous by the bright yellow colour of the anthers. The **fruit** is a capsule, splitting in June into two valves to liberate the ripe seeds, each of which has a tuft of hairs (aril, p. 349) at its base, by which it is dispersed by the wind.

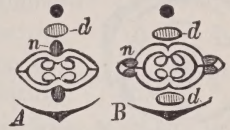
FIG. 297.—Black Poplar. 1, male inflorescence 2, female inflorescence; 3, male flower; 4, female flower; 5, fruit; 6, seed. (1 and 2, half natural size; 3-6, enlarged.) (After Strasburger.)

Poplars are wind-pollinated. The catkins are long and dangling when mature. The flowers (March to May) do not produce nectar, but each has a cup-shaped structure below the stamens or pistil, which may be the equivalent of the willows' nectary, or may be a much-reduced perianth. Since abundant pollen is required for wind-pollination, the flower of male poplars consists of numerous stamens (4 to 30), which are not conspicuously coloured. The pistil, fruit and seeds resemble those of the willow, and the seeds are similarly dispersed by the wind.

It will be evident that most of the differences between the flowers of willows and poplars are associated with the fact that the former are pollinated by insects and the latter by the wind.



Floral diagrams of male flowers of Willow (*Salix*). *A*, *S. caprea*; *B*, *S. purpurea*; *C*, *S. pentandra*. (After Eichler.)



Floral diagrams of female flowers of Willow (*Salix*). *A*, *S. caprea*; *B*, *S. alba*. (After Eichler.)

FIG. 298.

The vegetative features of willows and poplars are described on pp. 453 to 458.

49. SOME FAMILIES OF MONOCOTYLEDONS.

FAMILY LILIACEAE.

Plants recommended for study.—Tulip (*Tulipa*, April, May; earlier from florists), hyacinth or bluebell (*Scilla*, Apl.-June), star of Bethlehem (*Ornithogalum*, June, July; earlier from florists), garlic (*Allium spp.*, Apl.-Aug.), lily of the valley (*Convallaria*, May, June), meadow saffron (*Colchicum*, Aug.-Oct.), lilies (*Lilium spp.*, gardens, summer).

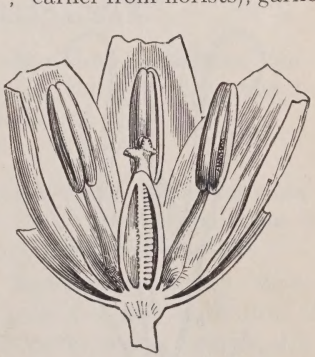


FIG. 299.—Flower of Wild Tulip (polyphyllous) cut in half longitudinally. The perianth leaves are shown cut short. (After Oliver.)

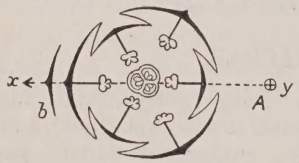
Distinguishing features.—Monocotyledonous herbs, perennating by bulbs (Fig. 145) or rhizomes (Fig. 302). **Leaves** lanceolate (tubular in onion and field garlic), sheathing, parallel-veined. **Inflorescence** usually a raceme (solitary and terminal in tulip and fritillary, a cymose raceme in onion and garlic). **Flower** often drooping, regular, hermaphrodite, *hypogynous*, with the parts in alternating whorls of three. **Perianth** leaves 3 + 3, hypogynous, usually joined at the base

(gamophyllous, *e.g.* hyacinth), but occasionally polyphyllous (*e.g.* tulip). **Stamens** 3 + 3 hypogynous (Fig. 299) or epiphyllous (Fig. 301), anthers usually introrse. **Gynaecium** tricarpellary, syncarpous; ovary *superior*, 3-chambered; placentation axile. **Fruit** usually an upright *capsule* opening at the top by 3 valves (*e.g.* lilies, bluebell, tulip, fritillary, star of Bethlehem, onion, garlic, meadow saffron), sometimes a *berry* (*e.g.* lily of the valley, Solomon's seal, butcher's broom, asparagus (Fig. 55), herb-Paris).

FIG. 300.—Floral diagram of polyphyllous Liliaceae.

Typical floral formula :

$$\overbrace{P_{(3+3)}}A_{3+3}\underline{G_{(3)}} \text{ or } P_{3+3}\ A_{3+3}\ \underline{G_{(3)}}.$$



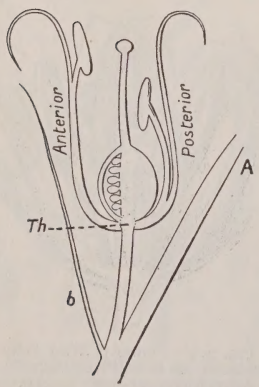


FIG. 301.—Floral diagram and longitudinal section of flower of Wild Hyacinth (gamophyllous).

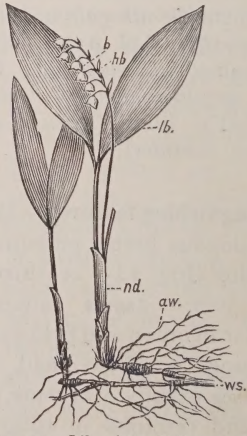


FIG. 302.—Lily of the Valley. *nd*, scale leaves; *lb*, foliage leaves; *b*, flower; *hb*, bracts; *ws*, rhizome; *aw*, adventitious roots. (After Strasburger.) ($\times \frac{1}{3}$.)

Pollination.—Most Liliaceae flower early, and are visited chiefly by long-tongued insects (butterflies, moths and bees), either

for nectar (formed in most cases in the ovary wall), or for pollen only (*e.g.* tulip, garlic). All six perianth leaves are usually large and brightly-coloured (petaloid), and the flower is often strongly scented.

A few British Liliaceae show interesting departures from the normal family characters. *Butcher's broom* is the only shrub among British monocotyledons ; its leaves are reduced to scales, photosynthesis being carried out by vertical ovate leaf-like branches or cladodes (p. 85) which bear the small greenish flowers. The plant is dioecious ; the male flower has only the 3 outer stamens ; the female flower has a single-chambered ovary. *Herb-Paris* (occurring locally in woods) bears only 4 leaves, which are whorled and *net-veined*. The single flower is terminal, yellowish-green, smells unpleasantly, is pollinated by flies, and has its parts in whorls of 4. *Asparagus* has small linear cladodes in the axils of the leaves, which are scaly ; the young shoots are eaten. *Meadow saffron* perennates by means of a corm, and flowers in autumn ; it is poisonous.

FAMILY AMARYLLIDACEAE.

Plants recommended for study.—Snowdrop (*Galanthus*, Feb.-Apl.) ; daffodil, jonquil, pheasant's eye (*Narcissus spp.*, March-May), snowflake (*Leucojum spp.*, Apl.-July).

Distinguishing features.—Monocotyledonous herbs perennating (in British species) by bulbs. They resemble Liliaceae in most respects, but are distinguished by the **inferior ovary**.

Leaves radical, parallel-veined. **Inflorescence** solitary (snowdrop, daffodil) or a cymose umbel (some narcissi) at the top of a radical peduncle (scape) bearing no leaves except a single, dry, membranous bract (spathe) which encloses the young flower or group of flowers. **Flower** drooping or horizontal, regular, hermaphrodite, epigynous, with the parts in alternating whorls of three. **Perianth** leaves 3 + 3, petaloid, epigynous, polyphyllous (snowdrop) or gamophyllous with a corona (daffodil and other narcissi). **Stamens** 3 + 3, epigynous (snowdrop) or epiphyllous (narcissi) ; anthers introrse or opening at apex. **Gynaecium**

tricarpellary, syncarpous; ovary inferior, 3-chambered; placentation axile. **Fruit** a capsule in British species.

Typical floral formula:

$$\overbrace{P_{(3+3)}}A_{3+3}\overline{G_{(3)}} \text{ or } P_{3+3}A_{3+3}\overline{G_{(3)}}.$$

[Floral diagrams as for Liliaceae.]

In the daffodil and other narcissi, the perianth tube is prolonged to form a **corona** beyond the level at which the spreading perianth lobes diverge. The corona is long and "glove-shaped" in daffodil, shorter in other narcissi, and a mere frill in pheasant-eyed narcissus (compare the rudimentary corona of some Caryophyllaceae and of forget-me-not, etc). The perianth of snowdrop is without corona. The history of a snowdrop bulb is described in detail in Chapter XII.

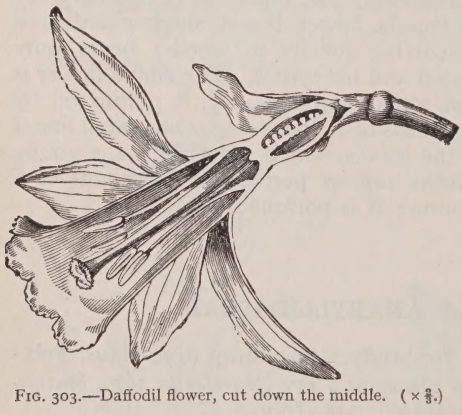


FIG. 303.—Daffodil flower, cut down the middle. ($\times \frac{2}{3}$.)

Pollination.—The *snowdrop* flower is visited by early hive-bees for pollen, as well as for the nectar secreted in the green grooves on the inner surface of the heart-shaped inner perianth leaves; the outer perianth leaves are white. Since the stigma projects beyond the anthers it is touched first by a bee entering the drooping flower from below, and may receive pollen adhering to the insect from a flower visited earlier. In reaching the nectar, the bee disturbs the stamens, the dry pollen being thus shaken from the terminal pores of the anthers on to its body, to be carried to another flower. Should cross-pollination fail, self-fertilisation may result from pollen falling on the stigma.

In the *daffodil* and other narcissi, the nectar is secreted at the base of the perianth-tube. It will be obvious from Fig. 303 that a humble bee crawling inside a daffodil corona to insert its proboscis between the bases of the filaments will rub against the stigma and the anthers in turn. The *pheasant-eyed narcissus* is white except for the short corona, which is yellow with a red

margin. The opening to its long and narrow perianth-tube is almost closed by the six anthers and the stigma, the nectar at the bottom of the tube being therefore accessible only to certain moths, which of necessity pollinate the stigma during their visits. The anthers and stigma are so close together, however, that self-pollination is almost inevitable.

FAMILY IRIDACEAE.

Plants recommended for study.—Crocus (gardens, Feb.-March), iris (May-Aug.), gladiolus (gardens, July-Sept.).

Distinguishing features.—Monocotyledonous herbs perennating by rhizomes (iris, Fig. 159) or corms (crocus, p. 217, gladiolus): Spanish iris has a bulb. Are distinguished from Amaryllidaceae by having only 3 stamens, which are epiphyllous. **Leaves** alternate, in two rows and folded in half lengthwise, vertical, parallel-veined. **Inflorescence** cymose, with spathes. **Flowers** hermaphrodite, regular (crocus and iris) or irregular (gladiolus), epigynous. **Perianth** leaves 3 + 3, petaloid, epigynous, gamophyllous. **Stamens** 3, epiphyllous, between and opposite the outer perianth leaves and the lobes of the style, therefore representing the *outer* of the two whorls found in typical monocotyledons; extrorse. **Gynaecium** tricarpellary, syncarpous; *ovary* inferior, 3-chambered; placentation axile. *Style* long, ending in 3 lobes. **Fruit** a capsule, opening by 3 valves.

FIG. 304.—Floral diagram of Iridaceae. (After Strasburger.)

Floral formula: $\overbrace{P_{(3+3)}}A_{3+0}\overline{G_{(3)}}$.

Pollination.—The *Crocus* flower is borne on a very short stem, so that the ovary remains beneath the soil. The perianth tube is very long and narrow, and is kept erect by the surrounding foliage leaves bound together by sheathing scale leaves (Fig. 305). Abundant nectar is secreted by the top of the ovary, and rises so high in the perianth-tube that it can be reached, not only by hibernated butterflies, but also by early bees. On visiting the

flower for nectar or pollen, the insects touch the 3-lobed stigma (*c*) before the extrorse anthers.

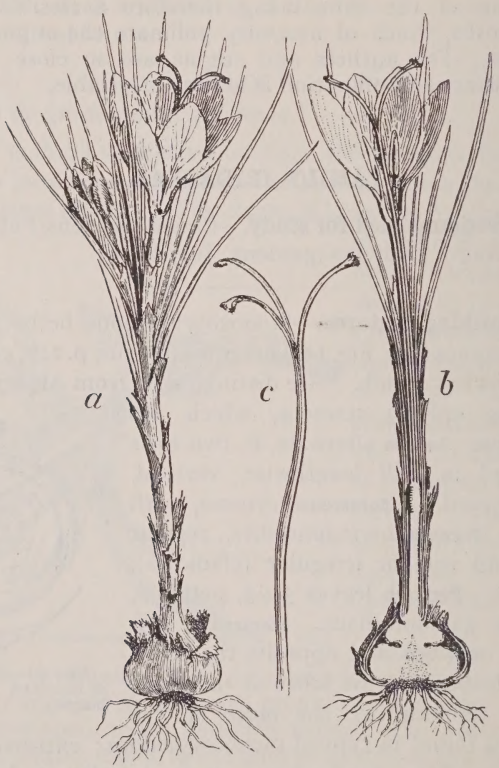


FIG. 305.—Saffron Crocus plant in flower. *a*, entire; *b*, in longitudinal section (× 4); *c*, three-lobed style. (× ½). (After Baillon.)

In *Iris*, each of the 3 petaloid lobes of the style arches over an outer perianth lobe, in the manner shown in Figs. 306 and 307, and then turns upwards. Just at the bend it bears on its lower (outer) side a small ledge-like scale, the upper surface of which is the true stigmatic surface (*st*, Fig. 307). Immediately below the stigma-scale, along its middle line, lies an anther (*a*), which bursts outwards. It will be seen that the parts are so disposed that a bee, alighting on one of the spreading outer perianth lobes (to the middle line of which it is kept by hairs as it makes its way to the nectar in the perianth-tube), will brush its head

first on the stigmatic surface (leaving pollen from a previously-visited flower) and then on the pollen-covered outer surface of the anther. On withdrawing, the insect will press the stigma-scale upwards and so prevent self-pollination.

Photo. Reginald Malby.

FIG. 306.—Flower of Iris. *o.p.l.* outer, and *i.p.l.*, inner perianth leaves; *sy.*, the three lobes of the style. The arrow shows one of the three paths by which a bee may enter in search of nectar.

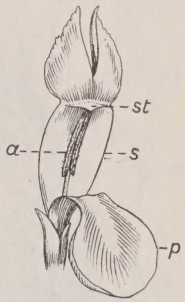


FIG. 307.—Iris. An outer perianth leaf *p*, with the opposite stamen and style-lobe *s*, seen from the front. *a*, anther; *st*, ledge-like stigmatic surface. (After Avebury.)

Gladiolus has a spike of zygomorphic flowers facing sideways. Insects alight on the lowest perianth leaf and, crawling along it, brush first against the projecting 3-lobed stigma and next against the anthers.

FAMILY GRAMINEAE.

Plants recommended for study.—(*a*) **Weed grasses.**—Annual meadow grass (*Poa annua*, Feb.-Oct., everywhere), common couch grass (*Triticum repens*, July, Aug., hedgerows), common bent or black twitch (*Agrostis vulgaris*, July, Aug., dry pastures). (*b*) **In hay-fields.**—Meadow foxtail (*Alopecurus pratensis*, Apl.-June, Fig. 190), meadow fescue (*Festuca pratensis*, June-Aug., Fig. 191), perennial rye grass (*Lolium perenne*, May-Aug., Fig. 189). (*c*) **Cereals.**—Wheat (*Triticum sativum*, midsummer, Fig. 308), barley (*Hordeum sativum*, July), oats (*Avena sativa*, June, Fig. 309).

Dissect the spikelets with mounted needles.

Distinguish between couch grass and perennial rye grass. In the former the flat face, in the latter the narrow face, of each spikelet is next the axis of the ear.

Distinguishing features.—Monocotyledonous herbs, some annual (oat, wheat, annual meadow grass, soft brome) but mostly perennating by rhizomes (*e.g.* couch grass) or runners (rough-stalked meadow grass, common bent). **Stem** with hollow inter-

Fig. 308.—Wheat. 1, ear, and 2, whole plant, of bearded wheat; 3, ear of beardless or "club" wheat. *a*, axis of ear; *b*, spikelet; *d*, flower; *c*, fruit (grain or "kernel"). (After Baillon.)

nodes (solid in maize, Figs. 95 and 109). **Leaves** alternate, two-ranked, usually with split sheaths and with ligules (p. 170), linear, parallel-veined. **Flowers** mostly hermaphrodite, in spikelets, enclosed by scaly bracts (glumes). **Perianth** absent, or doubtfully represented by two small scales. **Stamens** usually

three (the outer whorl), but only two in sweet vernal grass; hypogynous; filaments long and slender; anthers versatile, extrorse. **Gynaecium** monocarpellary; *stigmas*, two, feathery; *ovary* superior, one-chambered, containing one ovule. **Fruit** (described in Chapter I.) an achene with pericarp and seed-coat fused together.

Floral formula : $P_0A_{3+0}\underline{G}_1$.

The vegetative characters of grasses have been described on pp. 169 to 172.

Grass flowers.—The whole group of flowers borne by any one haulm or flowering branch is generally called the **ear** or **panicle.** The ear in its turn consists of many bodies called spikelets. The appearance of the ear varies greatly in different grasses, according as the stalks of the spikelets are (*a*) long and spreading outwards from the haulm, as in oats (Fig. 309), meadow grasses, fescues (Fig. 191), etc.; (*b*) short, as in foxtails (Fig. 190), timothy and sweet vernal grass, or (*c*) absent altogether, as in couch grass, wheat (Fig. 308), barley, rye and perennial rye grass (Fig. 189.

Fig. 309.—Branching raceme (panicle) of Oat. 51 spikelets are shown. ($\times \frac{1}{4}$.) (After Figuier.)

A single **spikelet** of a grass is shown diagrammatically in Fig. 310. At the bottom are two boat-shaped bracts called **glumes** (*g*, *g*), which almost or entirely cover the spikelet before it opens. When the glumes have been removed, a few (1-5) flowers remain. Their distinctive features are described above. Each is protected by two bracts called **pales** : outer (p_1) and inner (p_2) respectively. The outer pale is sometimes called the " flowering glume." It will be seen that the whole spikelet is a spike or short-stalked raceme. In many grasses the outer pale bears a bristle called an **awn**, well seen in oat, " bearded " wheat (Fig. 308), barley and upright brome grass. It may play an important part in distributing the " seeds " by clinging to the hides of animals, etc.

Sometimes (*e.g.* oat) the awn is hygroscopic, moving about as the air becomes drier or moister; and as the pales are barbed with stiff hairs, such movements tend to work the grain deeper and deeper into the herbage and so to the soil.

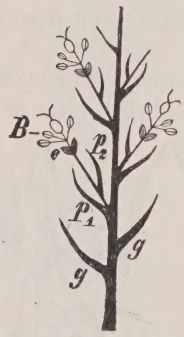


FIG. 310.—Diagram of a Grass spikelet. *g*, the glumes; p_1 and p_2, the outer and inner pales; *B*, flower; *c*, lodicules.

FIG. 311.—Meadow Fescue. *A*, spikelet with two open flowers (× 1½); *B*, a flower from which the outer pale has been removed (× 6). (After Schenck.)

The grass **flower** is well shown in Fig. 311. *A* represents a single spikelet of meadow fescue with two open flowers. *B* shows a single flower of the same grass from which the outer pale has been removed. The 3 hypogynous stamens and the 2 feathery stigmas are noteworthy. The two little scales seen in front of the ovary are called lodicules; they possibly represent the remains of a perianth.

FIG. 312.—Floral diagram of the Gramineae (Oat). The absent members are represented by X. (After Strasburger.)

Pollination.—The separation of the pales (*i.e.* the "opening" of the flowers) is brought about by the swelling of the lodicules. By this time the haulm has usually grown so tall that the flowers are lifted well above the leaves. The anthers of the stamens hang down on long filaments and, as the slender haulm sways in the breeze, the dry pollen is readily scattered and blown to the branched and

feathery stigmas of other flowers, perhaps miles away. In most cereals, however, self-pollination is usual.

Cereals.—Grasses producing seeds used for human food are called cereals. They include wheat, oats, barley, rice, maize and rye.

Recognition of the foregoing families.—With experience the student will soon be able to recognise the commonest families of flowering plants almost at sight, from their characteristic habits of growth, and more especially from their inflorescences. These indications should, however, be confirmed by a detailed examination of the flowers. The main differences between the 17 families considered in this chapter are shown in the following key, by help of which any flowering specimen *belonging to one of these families* may be easily classified. Keys on similar principles are employed in Floras,* from which not only these and other families, but also the genera and species, of our wild flowering plants may be determined.

		Refer to
1	The leaves are net-veined, that is, the plant is a Dicotyledon (pp. 52 and 209, footnote	2
	The leaves are parallel-veined, that is, the plant is a Monocotyledon	11
2	Catkin-bearing trees or shrubs	3
	Perianth leaves all separate, or (if sepals and petals are distinguishable) the petals are separate	4
	Petals united, at least at their bases	8
3	The tree or shrub bears *either* male *or* female flowers, but not both [**Salicaceae** (p. 409).]	
	The tree or shrub bears *both* male and female unisexual flowers [**Cupuliferae** (p. 408).]	
4 (following 2)	Petals and stamens hypogynous	5
	Petals and stamens perigynous	6
	Petals and stamens epigynous	7

* *e.g.* Watt's *School Flora* (Longmans), or (for beginners) Bonnier's *Name this Flower* (Dent).

5	Stamens numerous, carpels separate	Refer to [**Ranunculaceae** (p. 374).]
	Corolla cruciform, stamens 2 + 4.	[**Cruciferae** (p. 376).]
	Inflorescence a two-branched cyme, nodes thickened; stamens 5 or 10; carpels united below, 2-5 free styles.	[**Caryophyllaceae** (p. 378).]
	Corolla irregular; stamens 5; carpels united.	[**Violaceae** (p. 381).]
6 (following 4)	Corolla consists of standard, wings and keel (papilionaceous); stamens (9) + 1 or (10)	[**Leguminosae** (p. 384).]
	Stamens numerous; carpels separate	[**Rosaceae** (p. 388).]
7 (following 4)	Stamens numerous; ovaries 1-5, enclosed in thalamus - - -	[**Rosaceae** (p. 389).]
	Flowers in umbels. Stamens 5	[**Umbelliferae** (p. 390).]
8 (following 2)	Corolla hypogynous - - - -	**9**
	Corolla epigynous. Inflorescence a capitulum. Leaves alternate	[**Compositae** (p. 402).]
9	Flower regular. 5 epipetalous stamens opposite corolla lobes	[**Primulaceae** (p. 393).]
	Flower irregular - - - - -	**10**
10	Stem square. Leaves opposite. Flowers in axillary cymes. Fruit separating into 4 nutlets - - -	[**Labiatae** (p. 396).]
	Fruit a capsule; seeds numerous	[**Scrophulariaceae** (p. 399).]
11 (following 1)	Flowers without perianth and enclosed in scaly glumes - - -	[**Gramineae** (p. 417).]
	Perianth 3 + 3, petaloid - - - -	**12**
12	Ovary superior - - -	[**Liliaceae** (p. 411).]
	Ovary inferior - - - - - -	**13**
13	Stamens 3 + 3 - -	[**Amaryllidaceae** (p. 413).]
	Stamens 3 - - -	[**Iridaceae** (p. 415).]

EXERCISES XIX.

1. State (*a*) the chief points of resemblance and (*b*) the chief points of difference between any two kinds of buttercup you have examined.

2. Explain as precisely as you can the meaning of the statement that (*a*) creeping buttercups and lesser celandines are two species of the same genus, (*b*) buttercups and anemones are two genera of the same family.

3. Describe *three* types of flower met with in the Ranunculaceae. Show the special ways in which the examples you select are modified in relation to the mode of pollination.
(J.M.B. Sch. Cert.)

4. Describe, with examples, two different methods of pollination and of seed dispersal met with in the Ranunculaceae.
(J.M.B. Matric.)

5. Give an account of the structure and arrangement of the parts of L, illustrating your answer by enlarged drawings of each part. (L = *Helleborus niger*.) (C.J. Dec.)

6. Describe, chiefly by sketches, the various types of gynaecium met with in different members of the Ranunculaceae. Why are plants with these different arrangements classed together in the same natural order ? (L.M.)

7. Write an account of the range of floral structure found in the Ranunculaceae. State precisely the habitats of *six* British plants belonging to this family. (C.H.L.)

8. Give an account of the structure of the flower and fruit and the method of pollination in the Cruciferae. (J.M.B. Hr. Sch. Cert.)

9. Compare and contrast, by means of clear diagrams, the flowers of the greater stitchwort and the white campion, and say why these plants are included in the same family.

10. By what vegetative and floral characters would you recognise that a plant belonged to the family Caryophyllaceae ?

11. Describe in detail the method of cross-pollination in the pansy, illustrating your answer by a diagrammatic longitudinal section of the flower.

12. Dissect specimen A, draw and shortly describe its parts, and state their functions. [A = Sweet pea.] (C.J.)

13. (*a*) Draw on a *large scale* a longitudinal section of the flower provided [Birds-foot trefoil and Rest harrow].
(*b*) Identify it with the aid of a flora, and indicate the more important characters shown in the specimen, by which you are

able to determine (i) the natural order,* (ii) the genus, (iii) the species. Write at the end of your answer the author of the flora which you use. (O.S.)

14. Describe as fully as possible a wild rose bush as seen in June. Indicate concisely the chief differences in form between the flower of the rose and that of the buttercup. (N.F.U.)

15. Describe by means of labelled sketches the different forms of receptacle (thalamus) met with in the flowers of the Rosaceae. Sketch both flower and ripe fruit in each example selected. (L.M.)

16. Mention some characters which a bramble (blackberry) and a dog rose have in common, also some characters by which you could distinguish the two plants. (C.J.)

17. Give a general account of the various kinds of fruits met with in the family Rosaceae. (J.M.B. Hr. Sch. Cert.)

18. Describe, with sketches, the fruit Z. Express your opinion as to (*a*) the method by which the seeds are distributed, (*b*) the family to which the plant belongs. [Z = fruit of hawthorn.] (C.S. Dec.)

19. By examples taken from *either* Ranunculaceae *or* Rosaceae, show what is meant by *genus* and *species*. (J.M.B. Hr. Sch. Cert.)

20. Describe the vegetative and floral character of the Umbelliferae. What plants useful to man are included in this order? In each instance mentioned, state what part of the plant is used. (C.P.)

21. Explain clearly the significance of some primroses having long-styled and others short-styled flowers.

22. Mention any peculiarities in the arrangement of the stamens in the Primulaceae, and try to account for them.

23. From the Primulaceae describe a flower capable of being pollinated by short-tongued insects, and also a flower incapable of being pollinated in this way. How is the latter flower usually pollinated?

24. Give an account of the process of pollination in any *two* of the following plants: broom, primrose, pansy *or* violet, monkshood. (C.P.)

25. Show, by means of diagrams, the nature of a typical inflorescence of each of the following natural orders: Labiatae, Cruciferae, Caryophyllaceae.

26. By what features could you recognise a member of the Labiatae? Show, by means of diagrams, the structure of the flower in any labiate plant that you have studied. (C.P.)

* *i.e.* Family (see footnote, p. 373).

27. Describe, with the help of drawings, (*a*) the pistil and (*b*) the fruit of some member of the Labiatae, and explain how the seeds are dispersed.

28. Draw on a large scale a vertical section of any named flower. Name the parts of your drawing. (O.J.)

29. Dissect specimen M, draw and shortly describe its parts, and state the family to which it belongs. [M = Snapdragon.] (C.J.)

30. Make a floral diagram of the flower provided. Draw in median longitudinal section the principal stages represented in your specimen, beginning with the young unopened bud, to show the changes that occur as the flower opens and fades. [Foxglove.] (J.M.B. Hr. Sch. Cert.)

31. Give an account of the natural order Scrophulariaceae, stating what characters are distinctive of the order. Describe the methods of pollination found in the order. (L.M.)

32. Compare and contrast, by means of diagrams, the flowers of foxglove, mullein and speedwell. Give reasons for including these plants in the same family.

33. Within a genus of flowering plants very constant floral characters may be associated with a considerable range of variation in vegetative form. Illustrate this fact by specific detailed reference to any *two* genera which are known to you. (J.M.B. Hr. Sch. Cert.)

34. State concisely the differences between the Labiatae and the Scrophulariaceae.

35. Describe, with the aid of diagrams, the flower of a buttercup, and compare it with the flower of any member of the Rosaceae you have examined.

36. Give a careful account, illustrated by diagrams, of the floral structure met with in the Compositae, and describe the process of pollination in any member of this order that you may select. (C.P.)

37. Give a botanical description with sketches of the flower R, and assign it to its family. What is the probable method of pollination ? [R = *Centaurea Scabiosa*.] (C.S.)

38. What different types of flower are found in the Compositae ? Make a large-scale explanatory drawing of each type you mention, and add brief notes on its significance in pollination.

39. Describe fully the development of the fruit and the way in which the seeds are dispersed in one member of the Ranunculaceae, one member of the Scrophulariaceae, and one member of the Compositae. (O.S.)

40. Describe, mainly by labelled sketches, the fruits of the Compositae so as to illustrate as fully as possible the various methods of fruit-dispersal found in this order. (L.M.)

41. The plants of the daisy family are sometimes said to be the most highly developed of all the flowering plants. Choose two members of the family with which you are familiar, and point out some of the more interesting adaptations which they show. (N.F.U.)

42. What trees, common in Britain, are included in the family Cupuliferae? Why are they classified together, and apart from (*a*) the birch, (*b*) the poplar, (*c*) the horse-chestnut?

43. Mention trees whose flowers are respectively hermaphrodite, monoecious, dioecious. Explain these terms.

44. Compare the catkins and fruits of the oak and willow, with special reference to the methods of pollination and seed dispersal.

45. Describe, with the aid of drawings, the fruit of one plant you have examined from each of the following families: Cupuliferae, Compositae and Primulaceae. How are the seeds distributed in the plants you select for your description? (J.M.B. Sch. Cert. and Matric.)

46. Make sketches to show the differences between the flowers of willows and those of poplars, and explain how these differences are associated with differences in the method of pollination. Why are willows and poplars included in the same family?

47. How are the following flowers modified to ensure effective pollination: buttercup, primrose, dandelion, willow? Where necessary, sketches should be made to illustrate your answer. (Prel. Cert.)

48. Give a detailed description of a flower from each of *two* of the following families, showing how pollination is effected: Violaceae, Salicaceae, Leguminosae. (J.M.B. Matric.)

49. Describe, with the aid of drawings, the fruit of one British plant from each of the following natural orders: Salicaceae, Compositae, Labiatae, Primulaceae. Indicate in your drawings the position of the other floral organs or their remains or scars. Say in each case how the seeds are distributed. (J.M.B. Hr. Sch. Cert.)

50. Give an account of the floral structure and vegetative organs of any members of the Liliaceae you are acquainted with. (J.M.B. Hr. Sch. Cert.)

51. Describe some of the varieties of vegetative structure met with *either* in the Liliaceae *or* in the Rosaceae.

Show how the differences in form you describe are connected with the duration and mode of life of the plants. (J.M.B. Matric.)

52. By careful drawings of floral diagrams and of longitudinal sections through named flowers, show the essential resemblances and differences between the Liliaceae and the Amaryllidaceae.

53. Why are the following plants placed in different natural orders: (*a*) buttercup and rose, (*b*) daffodil and tulip, (*c*) snapdragon and dandelion? (N.F.U.)

54. By means of *labelled drawings only* indicate the structure of a ripe fruit from each of *two* of the following families: Umbelliferae, Scrophulariaceae, Amaryllidaceae. Describe the mode of dehiscence in each case. (C.S.)

55. Describe the flower of an iris. What are the characteristic features, floral and vegetative, of the Iridaceae? (C.P.)

56. Show with the help of drawings the form and relative position of the stamens and stigmas in an iris, and suggest an explanation of the arrangement you describe. (C.J.)

57. Compare with the aid of careful diagrams the flowers of the crocus and the iris. State why plants of so different an appearance are grouped together in the same family. (C.S.)

58. Describe the position of the nectary, and the way in which the honey is protected from insects which might take it without pollinating the flower, in *two* of the following: toadflax, iris, dead-nettle, primrose.

59. Make a series of annotated sketches, showing the vegetative and flower structures of any grass. (Cert.)

60. Give an account of the methods by which pollination is effected in the following: (*a*) the violet, (*b*) the pea, (*c*) the white dead-nettle, (*d*) a grass. (J.M.B. Matric.)

61. Give a general account of the vegetative and floral characters of *either* the Grasses *or* the Cruciferae; and mention the chief cultivated plants belonging to the family you select.
(J.M.B. Hr. Sch. Cert.)

62. Identify the specimens C, D and E, giving your reasons. Comment on any points of interest. You may use a flora.
[C = hairy willow-herb, D = hedge mustard, E = rye grass.]
(J.M.B. Hr. Sch. Cert.)

63. Draw, name, and briefly describe *three* examples of Monocotyledons, to illustrate the diversity of vegetative features met with in this group of plants.

64. Describe, with the aid of diagrams, *three* flowers adapted for pollination by wind. State in each case the time of flowering, and point out the advantages and disadvantages of this mode of pollination. (O.S.)

65. Describe three flowers the structure of which is adapted to pollination by special kinds of insects, and in each case give a detailed account of the mode of pollination.
(J.M.B. Hr. Sch. Cert.)

66. Name two common flowers much visited by bees ; describe in careful detail the adaptations which the flowers show to their insect visitors ; and indicate the importance of the visits to the plants. (N.F.U.)

67. What is meant by the term " apocarpous " ? In what natural orders studied by you is the gynaecium usually apocarpous ? Sketch an apocarpous gynaecium (*a*) in flower, (*b*) in fruit, from each of these natural orders. (L.M.)

68. By what means do the undermentioned flowers attract insects, and what do the insects obtain from the flowers : poppy, larkspur, wild rose, marsh marigold, elder, mignonette, broom, sweet pea ? (O.S.)

69. Discuss the significance botanically of any *three* of the following : the taking of " cuttings," rolling the soil after sowing, " thrashing " a cereal crop, the " rotation " of crops, weeding.
(C.S.)

CHAPTER XX.

SOME COMMON BRITISH TREES.

50. SYCAMORE, HORSE-CHESTNUT, ASH, LIME, ELMS.

The sycamore.—The sycamore, or great maple (Fig. 313), is one of the commonest trees in Britain (though it is not native), and it often grows to a great height. Its crown is of rounded and regular outline. The bark of the trunk ultimately becomes rough and flaky, but on most of the branches it remains smooth. Branched drooping stalks bearing green flowers spring from the tips of certain twigs in spring (Fig. 314). The flowers have five sepals, five petals, usually eight stamens, and a pistil; but in some the stamens, and in others the pistil, may remain imperfect (Fig. 218). Insects visit the flowers for the sake of nectar, and carry pollen from the stamens to the fertile pistils of other flowers. As a result a seed is formed in each of the two chambers of the pistil, the walls of the chambers growing out to form the flat wings of the fruit. This is described in detail in Chapter I. After the fruits are shed, the stalk on which they were borne falls from the end of the twig, leaving a saddle-shaped scar; and next spring the *pair* of axillary buds immediately beneath it grow out and the twig consequently forks.

Branching of this kind, consequent on the formation of a flower-bearing bud instead of a leaf-bud at the end of a twig, is called **false dichotomy**. It is found also in horse-chestnut, lilac, mistletoe, elder and privet.

The history of a sycamore twig for a year is described in detail on pp. 173 to 177.

The horse-chestnut.—The horse-chestnut differs from all our other trees of equal size in bearing brilliantly-coloured and conspicuous flowers. It is a large tree, somewhat conical in general outline, the trunk having moderately smooth bark, which

Photo. Henry Irving.

FIG. 313.—Sycamore, winter. On the right, a winter twig.

ultimately becomes somewhat scaly. The tree has a striking appearance at all seasons of the year. The leaves, often a foot in diameter, are opposite and decussate, palmately compound, consisting of seven—sometimes five—large, spoon-shaped leaflets which spring from a common point at the end of the leaf

stalk. They fall early, the leaflets being shed separately, and the leaf-stalks leaving large scars, which have some resemblance to the hoof-marks of a horse.

In winter the characteristic curves of the branches springing from the trunk—first upwards, then downwards, and then upwards again—are conspicuous, as also are the thick twigs, the large terminal buds and the opposite lateral buds (Fig. 315). The bud-scales are brown and soaked in sticky resin, which prevents loss of moisture and keeps out insects and the rain.

Photo. Henry Irving.

FIG. 314.—Sycamore. The unfolding (on the left of a leaf-bud; on the right of a flowering-bud).

The scales are the leaf-bases of otherwise undeveloped leaves, and the young foliage leaves inside are packed in down. The buds unfold early and the new shoots lengthen rapidly, so that the tree is a mass of foliage whilst most other deciduous trees are still bare. The flowers (Fig. 316) grow erect on branched stalks borne at the tips of certain of the new twigs. They open in May. Most of them are complete, containing not only stamens and pistil, but also a calyx and a beautiful pink, blue or white corolla. The pollen is carried from flower to flower by insects which visit them for nectar.

The globular fruit is ripe in October and then falls to the ground, its prickly husk splitting into three parts to liberate the two contained seeds. Their bitter taste and resemblance

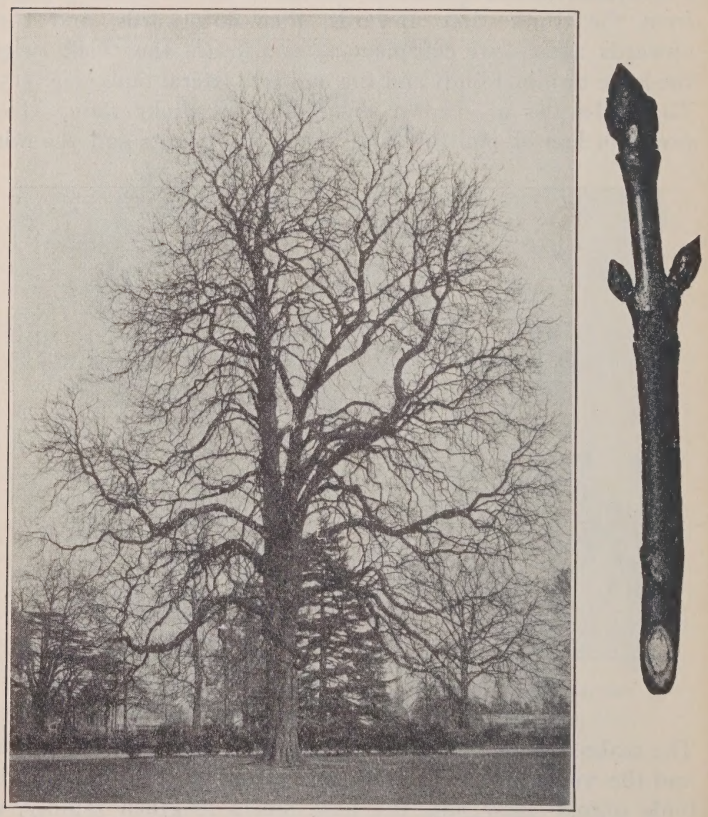


Photo. Henry Irving.

FIG. 315.—Horse-chestnut, winter. On the right, a winter twig.

to the nuts of the sweet chestnut—rather than the shape of the leaf scars—probably account for the name of the tree. Further *direct* elongation of a twig which has ended in a flower-cluster is impossible ; in such a case one or both of the last pair of lateral buds usually grows out next spring (Fig. 99).

The ash.—This tree flourishes especially on the limestone hills of the north and west of England. It is tall and very stately, and its opposite compound leaves—each consisting of about eleven leaflets, arranged in opposite pairs along the midrib, with a single leaflet at the end—give the foliage a characteristically feathery appearance. The bark is light grey in colour with neat upright fissures on the trunk. The branching is monopodial and the grey twigs are thick, more or less bending upwards at the ends, and curiously flattened at the nodes.

Photo. Flatters & Garnett, Ltd.

Fig. 316.—Leaves and flowers of Horse-chestnut.

The winter buds are black-olive in colour, and velvety. The bud-scales are leaf-bases; between them and the contained young foliage leaves are a few leaves in an intermediate stage of development. The flowers are close clusters, formed in *lateral* (axillary) buds, and come out in April before the leaves appear. They are small, without perianth, and when perfect have two purple-black stamens and a pistil. Their pollen is mostly carried by the wind. The fruits are long, each having a flat wing and containing a single albuminous seed (p. 10);

they hang together in bunches, known popularly as "keys" (Fig. 235). They are only detached by high winds, and may be blown to considerable distances. The leaves appear rather

Photo. Henry Irving.

FIG. 317.—Ash, winter. On the right, a winter twig.

late—about the end of May—on shoots growing out from the *terminal* buds, and are shed early. The ash belongs to the same family (Oleaceae) as the lilac and privet.

The **mountain ash**, or rowan tree, has leaves somewhat like

those of the ash proper, but alternate (Fig. 39); in other respects it is quite different, as it belongs to the Rosaceae.

The lime.—The lime tree (Fig. 320) has a straight and almost smooth trunk. The crown generally spreads at the base and tapers to a blunt apex. The leaves (Fig. 321) have early-shed stipules, are alternate, two-ranked, stalked, bright green,

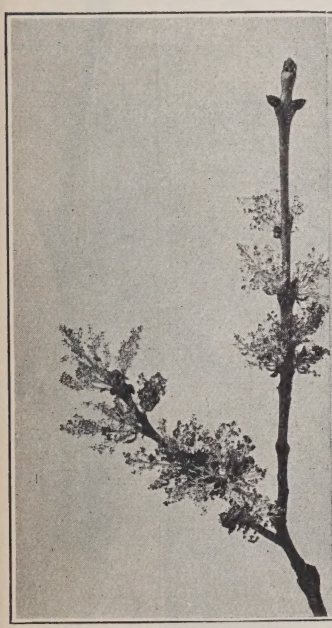


FIG. 318.—Ash Flowers.

Photo. Henry Irving.

FIG. 319.—Two Ash Leaves.

simple, heart-shaped with pointed apex, pinnately net-veined, and plainly larger on one side of the midrib than on the other. They appear in late spring and fall early in autumn. The twigs are red, slender, and zigzag from node to node. The terminal bud falls off in September or earlier, leaving the growth to be continued next spring by the last axillary bud, which is practically at the same level; the branching of the tree is therefore sympodial (p. 148). Only two scales are visible on the outside of a winter bud; each is perhaps equivalent to a pair of stipules

fused. The flowers of the lime open at midsummer; they are yellowish-green, in clusters carried on a stalk which bears a long, narrow and pale-green bract (Fig. 321). Calyx, corolla, numerous

Photo. Henry Irving.

FIG. 320.—Lime, winter. On the right, a winter twig.

stamens and pistil are all present, and the flowers are pollinated chiefly by hive-bees, which visit them for the sake of the abundant nectar they contain, and are attracted by the sweet scent. The light-coloured bract ("wing") possibly makes the flower-clusters more conspicuous to the insects, and it assists in the dispersal by wind of the resulting bunch of globular nuts—the

bract and the depending fruits being detached together in autumn. Lime bast is used for making mats, tying up garden plants, etc.

The elms.—In Great Britain two species of elm occur. In the southern and midland counties *Ulmus campestris* is the more abundant—it is known as the common elm; in the north and in Scotland the wych elm (*Ulmus montana*) is much more frequently found. Both elms are tall, with crowns broadest near the top (Fig. 322). They have straight trunks with thick and deeply-fissured corky bark, especially marked in the common elm, the

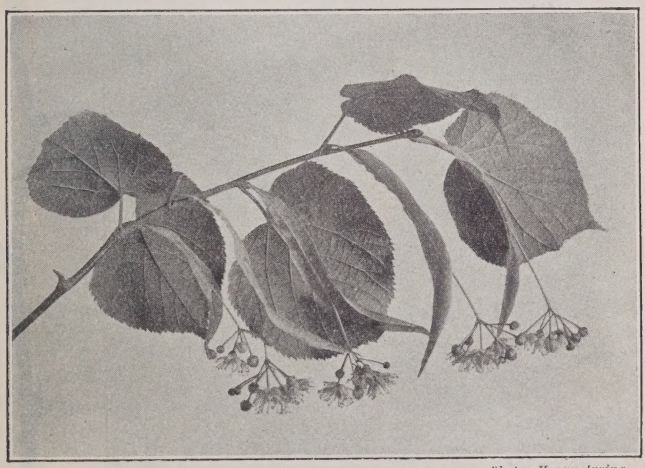


Photo. Henry Irving.

Fig. 321.—Lime leaves and flowers.

twigs also of which are sometimes thickened with irregular ridges of cork. The common elm has broadly ovate leaves, about $1\frac{1}{2}$ inches long, with short stalks (Fig. 323); the wych elm's leaves are 3 or 4 inches long, proportionately narrower, and practically sessile (Fig. 34). The leaves of both are rough to the touch, being clothed with small, stiff hairs, and have very prominent veins which form a pinnate network. The margin is biserrate. The side of the blade nearer the tip of the twig extends lower down the midrib, producing a marked lop-sidedness, which is especially distinctive of wych elm leaves, and aids in forming a close mosaic (Fig. 34). The leaves are

alternate, two-ranked and stipulate when they first upfold. The buds are small, brown, conical and hairy, and each axillary bud leans a little to one side of the base of the subtending leaf.

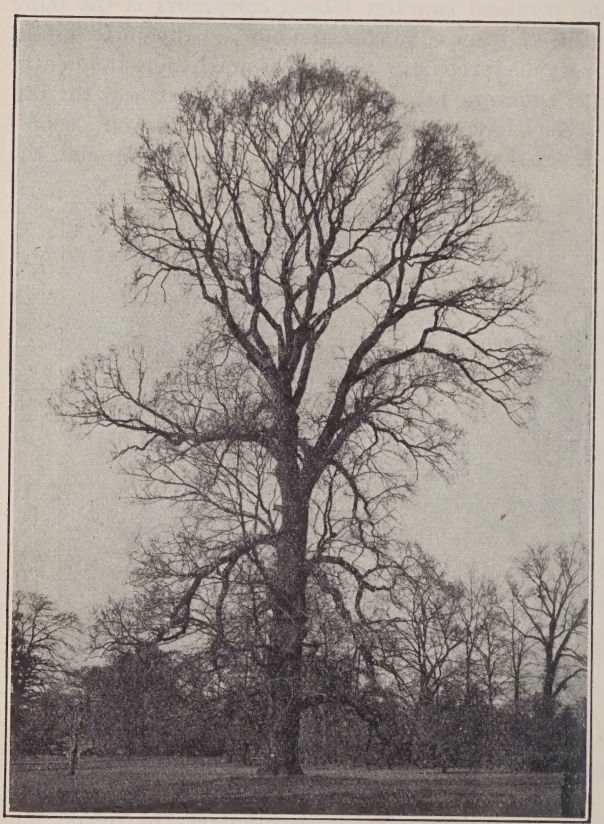


Photo. Henry Irving.

FIG. 322.—Common Elm, winter. On the right, a winter twig.

The bud-scales are the stipules of imperfect leaves. The terminal bud is regularly shed in autumn, the new "leader" being produced from the last formed axillary bud, as in the lime.

The small flowers make their appearance in March or April as rounded clusters emerging from the largest axillary buds,

before the leaf-buds have unfolded. They are purple and contain both stamens and pistil, surrounded by a 4- or

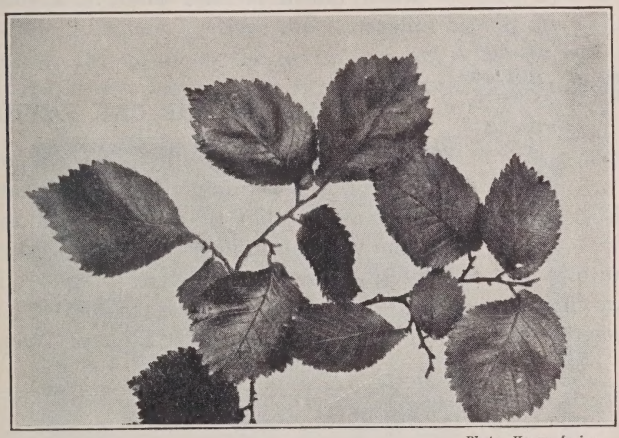


Photo. Henry Irving,

FIG. 323.—Leafy branch of Common Elm.

6-lobed calyx. They are cross-pollinated by the wind, the pistil maturing before the stamens of the same flower. The fruits are samaras (p. 352), the seed-case being in the centre of an oval plate about 1 inch in length in the fruit of the wych elm, but a little beyond the centre of a notched rounded plate some half-inch in diameter in the common elm (Fig. 325). The fruits are dispersed by the wind from May onward. In Great Britain the seeds of the common elm do not germinate, and the trees, when left to themselves, increase in number by numerous suckers. A line of young trees, produced in this way,

FIG. 324.—Wych Elm: leaves, flowers and fruit. 1, flowering branch ($\times \frac{2}{3}$); 2, branch with leaves; 3, a flower ($\times 2$); 4, the same, cut through longitudinally; 5, a fruit ($\times \frac{2}{3}$). (After Strasburger.)

may often be seen on either side of an old elm in a hedge. On the other hand, the seeds of the wych elm germinate freely when blown by the wind to a suitable place.

FIG. 325.—Fruits of Common Elm ($\times \frac{1}{2}$). (After Strasburger.)

51. TREES OF THE OAK FAMILY.

Trees of the oak family.—The oak, beech and sweet chestnut have so many features in common that they are grouped in one family (the Cupuliferae), the general characters of which are described in Chapter XIX. (p. 408). Here we are chiefly concerned with the more easily recognisable habits of growth which distinguish these from other common trees.

Photo. Henry Irving.

FIG. 326.—Common Oak, winter (Windsor Great Park).

Common oaks.—A solitary oak is easily identified from a distance by its gnarled and wide-spreading boughs, which often spring almost horizontally from the trunk. The general shape

of the crown is hemispherical. The trunk is often very thick at the ground level, and then rapidly narrows until, at a height about equal to the base-diameter, it may be only half or one-third the thickness. Above this point it is practically cylindrical up to the origin of the lowest boughs, where it is swollen. The bark is very rugged, with ridges and furrows running almost

Photo. Henry Irving.

FIG. 327.—Sessile Oak: leaves and fruit. On the right, a winter twig.

vertically (Fig. 107). The leaves come out in May, are alternate, with a phyllotaxis of $\frac{2}{5}$ (p. 49), and have stipules which are shed early. The general shape of the oak leaf (Fig. 327) is spathulate, and the margin is deeply lobed; the veins form a pinnate network. The later internodes of each season are very short, so that the leaves form a rosette at the end of the twig. It follows that the upper 4 or 5 axillary buds, which are small and egg-shaped, are very close together behind the apex. A crowded oak may long

remain monopodial (with a straight main trunk), but usually the terminal bud dies, and the last axillary bud continues the growth of the twig. Often the lower axillary buds on each year's growth remain dormant. The bud-scales are the stipules of the stunted last leaves of the season.

The oak rarely flowers before it is 50 years old; the flowers develop in buds which also contain leaves, and the

Photo. Henry Irving.

FIG. 328.—Branch of Holm Oak, with acorns.

flowers and leaves unfold together. As the bud opens, catkins of male flowers appear in the axils of the upper bud-scales; ordinary foliage leaves with buds in their axils emerge next; then leaves with catkins of female flowers in their axils; and, finally, another group of foliage leaves with axillary buds. The male catkins are 2 or 3 inches long; each bears about a dozen male flowers and hangs down so that the pollen is readily scattered by the wind. The female catkins are small and stiff, the female flowers (one to five) on each are about the size of

pin heads. Their spreading stigmas catch the wind-borne pollen, and in due course each flower forms an acorn, with the familiar cup.

In one variety of oak, called the "**pedunculate** oak," the acorns are stalked (Fig. 293); in the "**sessile** oak," on the other hand, the acorns are without stalks (Fig. 327). The leaves of the two varieties are in opposite case, those of the pedunculate oak being practically sessile, while the leaves of the sessile oak have well-developed stalks. It should be noticed that the descriptive adjective of the two varieties refers to the acorns, not to the leaves.

Galls of various kinds are to be found on most oaks. They are excrescences caused by the irritation of certain insects laying their eggs in the soft tissues beneath the surface.

The **evergreen** or **holm oak** (sometimes called the holly oak) is frequently cultivated in parks. It has ovate and often toothed leaves, with a dark-green glossy upper surface and a grey lower one. The leaves transpire very slowly, having a thick cuticle, and remain on the branch for two years, falling in spring. The twigs of the holm oak—like those of other evergreen trees and shrubs (pp. 86, 173, 274 and 460)—thus differ from twigs of deciduous trees, not only in winter, but also in summer, by retaining *leaves on the previous season's growth.* It will be remembered (p. 174) that the leaves of deciduous trees are *ipso facto* restricted to the portion of each twig which has grown out during the current season.

The beech.—Beeches are peculiarly at home on the chalk downs (p. 285), but are planted in many other parts of the country. The tree is easily recognised by the olive-grey, smooth bark, the "buttressed" base of the trunk, the glossy green leaves in summer, and the long, pointed buds in winter. When well grown, the beech is lofty, with an egg-shaped crown of branches (Fig. 329). The leaves are stalked, smooth, simple, ovate, pinnately net-veined, with a slightly wavy margin, and are arranged alternately in two rows along the slender, zig-zag twigs. At first the leaf is fringed with silky hairs, and bears a pair of strap-shaped stipules, which are shed almost as the buds open. The leaf-stalks twist when necessary to bring the leaves to face the light directly; by this means and the arrangement of the young twigs

among themselves, the beech possesses the most perfect leaf mosaic among forest trees (Fig. 330), and casts so dense a

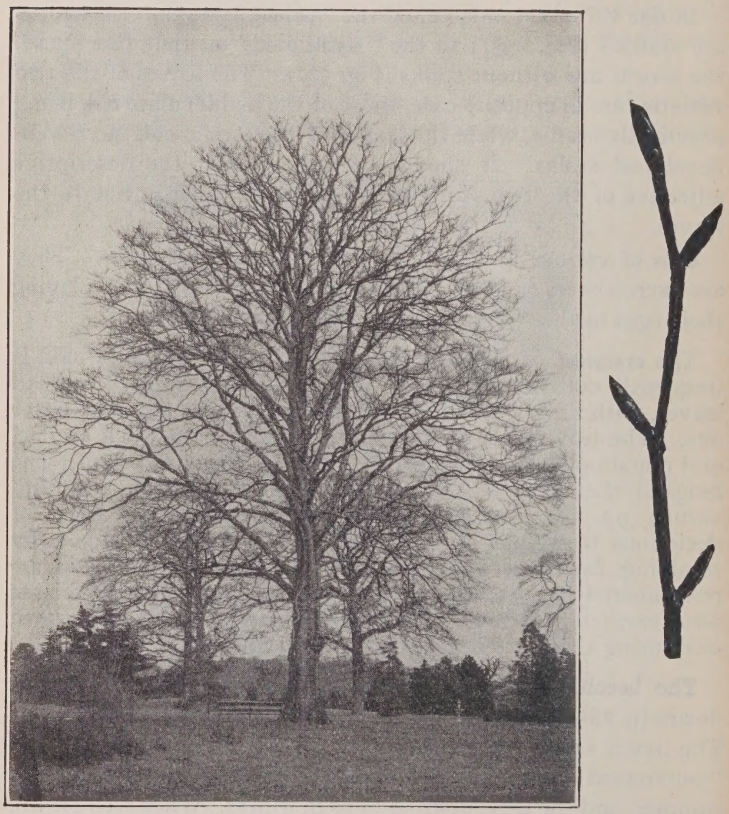


Photo. Henry Irving.

FIG. 329.—Beech, winter. On the right, a winter twig.

shade that the ground beneath is generally destitute of green vegetation.

The buds are cigar-shaped and stand out from the twig at an angle of about 60°, each a little to the upper side of the base of its subtending leaf. In most cases the terminal bud on each twig is shed and the adjacent lateral bud forms the next "leader."

The brown, papery bud-scales are stipules only, in four rows; next inside come a few pairs of stipules with small leaf-blades, and in the middle of the bud the perfect young leaves form the foliage of spring (Fig. 54). The buds near the base of a twig usually remain undeveloped; most of those higher up form new twigs of the usual type, but here and there one becomes a "dwarf shoot," the internodes of which scarcely elongate at all, so that they may not be more than an inch in length when

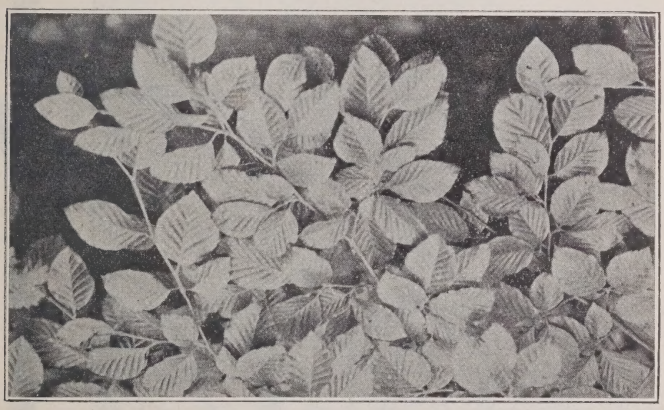


Photo. Henry Irving.

FIG. 330.—Leaf mosaic of Beech.

(as the scale-scars show) they are six or seven years old (Fig. 100). Young beeches, like young oaks, often retain their leaves through the winter.

The tree is in flower by the time the foliage has fully developed. The male flowers (Fig. 294) are borne in small, rounded, stalked, hanging catkins, each of which arises in the axil of a leaf. Nearer the tip of the twig, axillary female catkins grow out; these are shorter and stand upright, and each consists of a pair of female flowers surrounded by a cup. After fertilisation by the wind-borne pollen of the male flowers, the two female flowers give rise to two three-sided nuts, enclosed in the four-lobed cup, which, when the nuts are ripe, is woody and covered with hard, blunt prickles. It splits into four parts to liberate the nuts.

In the **copper beech**, the green of the chlorophyll, which the leaves possess as usual in their mesophyll cells, is disguised by a reddish colouring matter dissolved in the sap of their epidermal cells.

Photo. Henry Irving.

FIG. 331.—Spanish Chestnut, winter. On the right, a winter twig.

The **Spanish** or **sweet chestnut** belongs to the same family as the oak and beech, but is not native in Britain. The trunk is straight, erect and sturdy, and noticeably tapering from base to summit. The bark is thick and strongly ridged, the furrows being at first vertical, but later tending obliquely and forming a spiral pattern round the bottom of the trunk. The leaves

(Fig. 332) are long, narrow, serrate, alternate, seven to nine inches long, with early shed stipules. The tree flowers in July. Its fruit is enclosed in a prickly husk (corresponding to the cup of an

FIG. 332.—Spanish Chestnut. Leafy twig, bearing flower-clusters. (× ¼.). (After Baillon.)

acorn) which splits into four when the nuts are ripe in October. The winter twigs are rather thick and straight, with alternate buds, each with only two scales showing at the surface.

52. TREES OF THE BIRCH FAMILY.

The birch, hazel, alder and hornbeam are closely allied to the oak family, but on account of certain constant differences are not now included in it.

Birches.—These slender, graceful trees are native in the British Isles. Their thin papery bark is streaked with brown, yellow and silvery patches. The lenticels are transversely

elongated. The leaves are rather small, simple, long-stalked, with deciduous stipules; they are ovate, triangular or diamond-

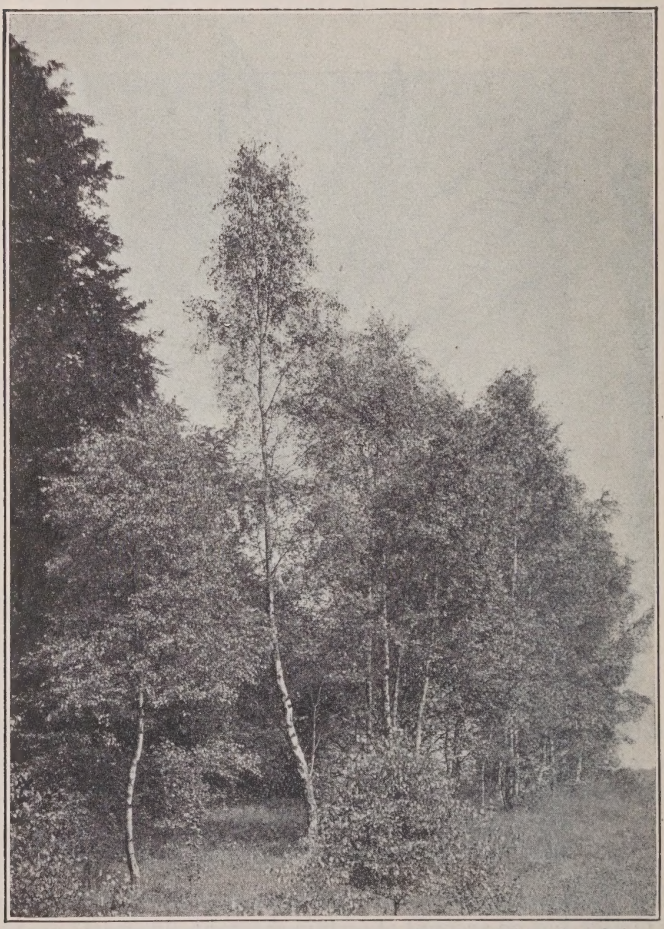


Photo. Henry Irv'n J.

FIG. 333.—Birches growing on the border of a wood.

shaped, and have pointed tips and a biserrate margin. They are arranged spirally on the very slender twigs, and do not cast much shade (p. 281). In other words, they do not intercept much

light, and therefore birches cannot endure thick woods. The buds are small and pointed, and their scales consist of stipules. The terminal bud of the twig dies, to be succeeded as leader by the nearest axillary bud. Certain lower buds produce dwarf shoots, as in the beech bearing rosettes of leaves without axillary buds. Both male and female flowers grow on the same tree; they are arranged in cylindrical catkins. The male catkins appear in August, and are to be seen on the trees throughout the winter (Fig. 334). In March or April (before the leaves

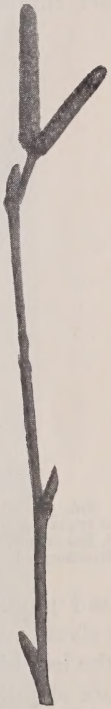


Fig. 334.—Birch. 1, branch with terminal male catkins, and female catkins on small lateral branches; 2, female flower; 3, male flower; 4, stamen; 5, a catkin in fruit; 6, fruit. (1 and 5, $\times \frac{1}{2}$; 2-4 and 6, enlarged.) (After Strasburger.) On the right, a winter twig.

Photo. Henry Irving.

appear) they lengthen and hang down, and their pollen is discharged and blown to the erect and much smaller female catkins, which have newly grown out and opened. During the ripening of the seeds, the female catkins grow larger, and hang from the twigs. In autumn the tiny fruits—each a doubly winged achene—are shaken out and dispersed by the wind.

The hazel.—The hazel is a shrub common in oak woods and hedges. It often forms no main trunk, but its stem branches freely near the ground; and new shoots (stool shoots) continue

to spring from the base, and quickly grow upwards. The root system is meagre and shallow, and suckers are commonly formed. The leaves are alternate, usually two-ranked on the horizontal shoots, but three-ranked on the stool-shoots and suckers. They are simple, shortly stalked, heart-shaped, irregularly toothed,

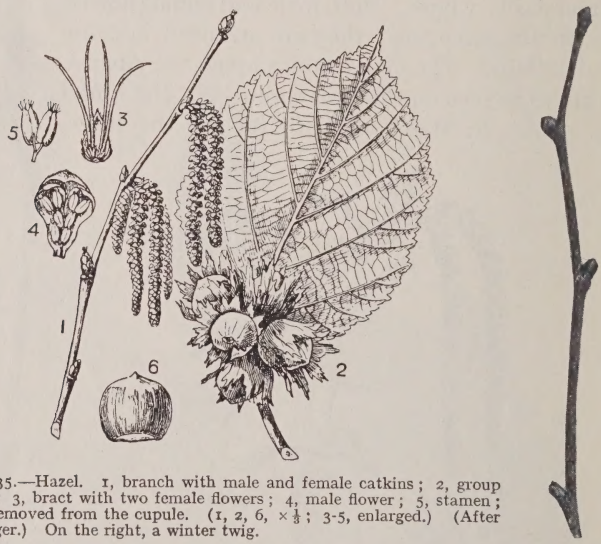


FIG. 335.—Hazel. 1, branch with male and female catkins; 2, group of fruits; 3, bract with two female flowers; 4, male flower; 5, stamen; 6, fruit removed from the cupule. (1, 2, 6, × ⅓; 3-5, enlarged.) (After Strasburger.) On the right, a winter twig.

Photo. Henry Irving.

and pinnately net-veined. When young they are soft and velvety to the touch and have stipules, which are shed early, but the leaf-blades soon become harsh and hairless; the leaf-stalks are slightly sticky. The winter twigs are covered with hairs and are zig-zag from node to node, with axillary buds of a flattened egg-shape. The bud-scales are stipules.

The branching is sympodial, since the terminal bud dies at the end of the summer. Certain of the new axillary buds grow out even in summer—before the leaves have fallen—to form twigs bearing stiff cylindrical male catkins, and these are to be seen on the leafless branches in winter. In the very early spring—usually in February—they elongate and hang down, and their flowers open and discharge the pollen. At the same time the egg-shaped groups of female flowers emerge from buds on the

same prematurely developed twig (Fig. 335, *1*). Their brilliant red stigmas receive the wind-borne pollen dust, and the most vigorous female flowers produce each a nut, enclosed by a

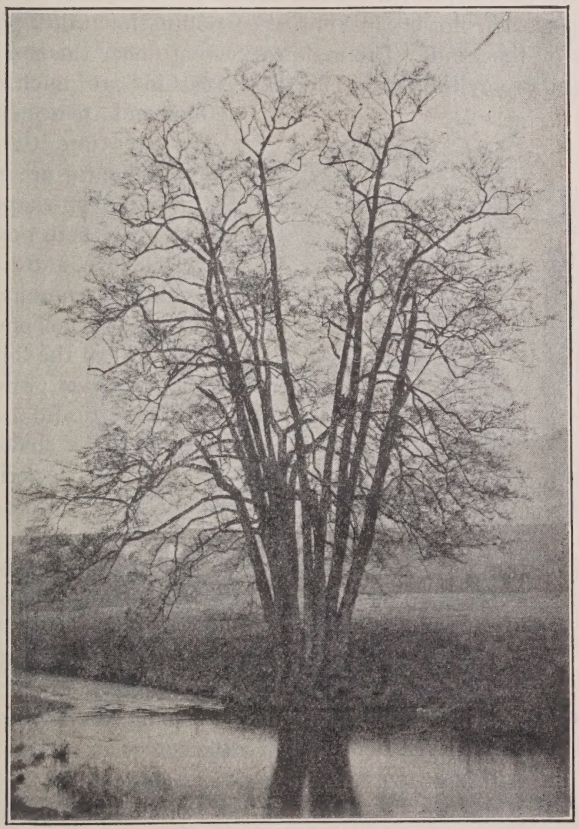


FIG. 336.—Alder, winter. *Photo. Henry Irving.*

sheath of soft bracts. The contained seed is without endosperm, but its cotyledons are swollen with food. The ordinary leaf-buds do not unfold until some weeks after the flower-buds.

The alder.—Chiefly found on the banks of streams and ponds, or in marshy places, the alder is not usually a large tree; it has a tendency to the shrubby habit and the formation of stool shoots.

The leaves are smooth and very broadly spoon-shaped, with a somewhat toothed margin; they bear deciduous stipules when young. Some of the axillary buds grow out in late summer to form the catkins, which remain on the twigs through the winter and open their flowers in February; pollination takes place by means of the wind. The male catkins are near the end of the twig and are cylindrical. The female catkins are much smaller at first and are egg-shaped.

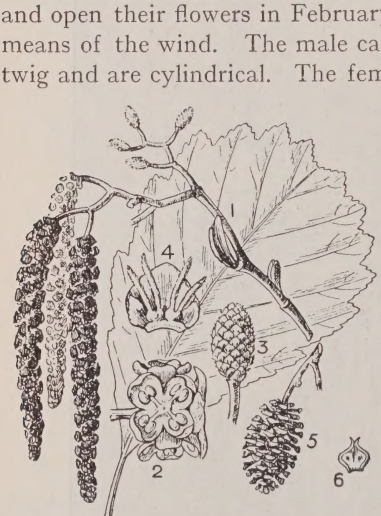


FIG. 337.—Alder. 1, flowering branch bearing the small, erect female catkins and the dangling male catkins; 2, a bract scale with male flowers; 3, female catkin; 4, female flower; 5, catkin in fruiting condition; 6, fruit. (1 and the leaf, $\times \frac{1}{2}$; 2-6, enlarged.) (After Strasburger.)

By the time the small fruits (achenes) are ripe in autumn, the egg-shaped catkin has grown to nearly an inch in length, and its scaly bracts have become hard and woody. The achenes are not shed until the following spring, however, when the scales separate and the fruits can drop or be shaken out by the wind. The pericarp is spongy, and if the achenes drop into water, they may float away to some distance, and so disperse the seeds. A winter twig of alder thus may bear two stages of female catkins as well as the male catkins and the ordinary leaf-buds. These last are peculiar in being stalked and not sessile as the resting buds of our other trees are. The winter twigs and buds are covered with a waxy bloom.

The hornbeam.—The leaves of the hornbeam (Fig. 218) are somewhat like those of the beech in shape, but with a serrated margin destitute of silky hairs, and a dull surface. The winter twigs are slightly hairy, and the alternate resting buds are short and conical. The flowers are similar, except in detail, to those of the hazel, to which the tree is much more nearly related than to the beech. The fruit is a pair of nuts, each nut attached to a large trilobed bract, which aids in its dispersal by the wind.

53. WILLOWS AND POPLARS.

Willows and poplars being dioecious are grouped together in the family Salicaceae, and thus separated botanically from other catkin-bearing trees; their catkins and flowers are described on pp. 409 to 411. Both willows and poplars are chiefly found growing near water.

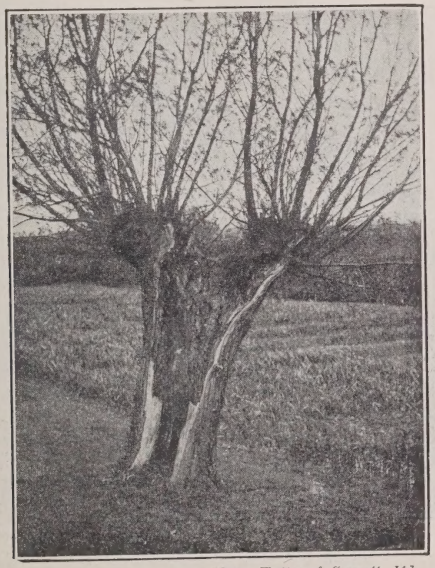


Photo. Flatters & Garnett, Ltd.

FIG. 338.—Old Pollard Willow.

Willows.—Considerable variation in size is shown by willows, some species growing to be tall trees, while at the other extreme certain creeping or dwarf willows (Fig. 167) barely rise above the level of the ground. Willows have usually long and flexible twigs, ridged below each of the spirally arranged leaves, which bear early-shed stipules. The pointed axillary buds are pressed closely against the twig, and show only one scale at the surface; some of the buds form catkins and others leafy shoots. The

branching is sympodial (Fig. 98). The bark of fully grown willows is thick and much ridged.

Narrow-leaved willows.—The commonest species are the **crack willow** (withy) and the **white willow.** The former owes its name to the ease with which the young twigs snap off cleanly at the base. Both have long (4-6 in.), lanceolate, serrate leaves, pinnately net-veined, smooth and shining in the crack willow, but covered, especially on the lower side, with white silky hairs in the

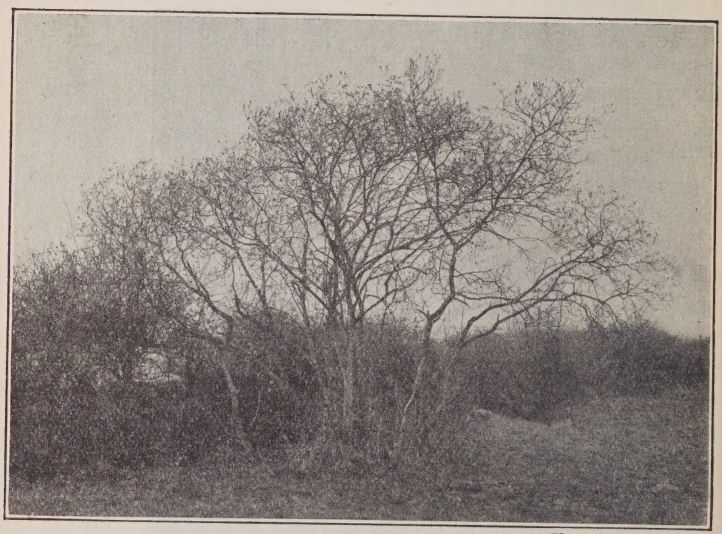


FIG. 339.—Goat Willow. *Photo. Henry Irving.*

white willow (Fig. 98). These and other long-leaved willows—especially the common osier and purple osier, which are shrubs—have a marked tendency to produce long tough shoots called **osiers**, used in basket-making. This tendency is encouraged by the practice of pollarding, in willows, such as white willows, which would otherwise grow into trees.

Broad-leaved willows.—The commonest of the broad-leaved willows is the **sallow**, goat willow, or "palm." Its twigs are too short and thick to be used as osiers, and its buds are larger than in other species. The leaves (Fig. 340) are wrinkled and

spoon-shaped or ovate, and end in a twisted tip; the upper surface is smooth and deep-green, the lower surface downy and bluish. The ear-shaped stipules are exceptional in remaining on the leaf. The flowers of the sallow produce a marked abundance of nectar, and form one of the chief sources of honey and pollen for hive bees in March and April. The female catkins are unusually long.

Photo. Henry Irving,

FIG. 340.—Goat Willow. Summer and winter twigs.

The poplars.—The commonest poplars in Great Britain are the aspen and white poplar or abele, which are native, and the black poplar and Lombardy poplar, which are introduced. The aspen and black poplar are alike in having their leaf-stalks flattened at right angles to the blade, a feature which causes the leaves to turn from side to side with the slightest breeze, making a pattering sound and giving the foliage a very characteristic

" twinkling " appearance. Both these trees have thin twigs and both are common near water, and it is supposed that the incessant side-swing of the leaf is of advantage by lessening the resistance

Photo. Henry Irving.

FIG. 341.—Black Poplar, winter. On the right, a winter twig.

to the wind (and therefore the risk of fracture of the twigs), and also by promoting transpiration. On the other hand, such leaves do not receive so much sunlight as normal horizontal leaves, and this may be the reason why the aspen and black poplar are rarely found growing actually in woods. Like

birches (p. 449) they only thrive in well-lighted situations. The leaf-stalks of the white and Lombardy poplars are not flattened, and the leaf-blades are more or less horizontal; moreover, the twigs are thick; and it is significant that both these trees endure shade better than the aspen and black poplar.

Poplars in general have loose and straggling branches, and often a lop-sided crown. The leaves are spirally arranged, with stipules which fall early. The blades are net-veined. In the aspen they are nearly circular and usually bluntly serrate, green above, greyer below; in the white poplar they are palmately lobed, smooth and deep-green above, but with a felt-like covering of white hairs below. The leaf-blades of the black poplar (Fig. 342) are more or less triangular, with a long, pointed apex, a serrate margin, and both sides smooth and light green. The axillary buds have 4 outside scales, that on the front of the bud being slightly concave (Fig. 341). They are pointed, sticky, and closely pressed to the twig in the aspen and black poplar; they are downy in the white poplar. The true terminal bud does not develop, but the last axillary bud continues the length of the twig. The catkins are produced, before the leaves, from the larger axillary buds of the previous season's growth. The black poplar often sheds whole twigs as well as the leaves, in autumn, an "absciss layer" (p. 174) being formed in each case.

FIG. 342.—Black Poplar. 1, male inflorescence; 2, female inflorescence; 3, male flower; 4, female flower; 5, fruit; 6, seed. (1 and 2, half natural size; 3-6, enlarged.) (After Strasburger.)

The Lombardy poplar (Fig. 343) is often supposed to be a variety of the black poplar. It owes its well-known spindle or spire shape to the excessive negative geotropism of the side branches, so that they grow vertically upwards, parallel to the main stem. Its bark is very deeply furrowed. Like the black

poplar, it very readily forms suckers, and therefore often occurs growing in rows (compare common elm, p. 439). All

Photo. Henry Irving.

FIG. 343.—Lombardy Poplar, winter.

the Lombardy poplars growing in Britain appear to be staminate or "male" trees, derived by repeated vegetative propagation from a tree introduced in 1758.

54. THE SCOTS PINE AND THE LARCH.

The gymnosperms.—The Scots pine and its relatives the firs, larches, juniper, yew, etc., are true flowering plants; but their

Photo. Henry Irving.

FIG. 344.—Scots Pine.

flowers differ greatly from those of dicotyledons and monocotyledons, in that the modified leaves called carpels are not folded, or joined edge to edge, so as to shut up the ovules in a closed ovary—as in all the flowers we have previously studied—but remain more or less flat, so that the ovules are exposed on their

surface, and the pollen gains access to them directly, instead of being received on a stigma. Plants with flowers of this character are called **Gymnosperms**, a word meaning "naked seeds"; while dicotyledons and monocotyledons are classed together as **Angiosperms**, because they have enclosed seeds. Such gymnosperms as pines, firs, and larches, the flowers of which are cones, are called *Conifers*.

The Scots pine.—This is a large tree with a dome-shaped crown of foliage when fully grown. The general structure of the stem is broadly like that of a dicotyledon tree. It forms secondary wood and bast, and has rough, scaly bark (Fig. 102). It is a monopodium (p. 148), its growth being continued by a true terminal bud, but it has two kinds of branches. The obvious **branches of unlimited growth** or long shoots are formed in whorls each spring by the development of three or four buds just below the terminal bud. The fact that the twigs of any one year all grow out at practically the same level makes it very easy to date the various portions of a branch of this tree. These long shoots (Fig. 345, *1*) bear no foliage leaves *directly*, but only scale leaves. The **branches of limited growth** (also called dwarf shoots) are formed in abundance in the axils of the small scale-leaves which grow on the younger long shoots. These dwarf shoots are merely little stumps, bearing each a pair of long, needle-shaped *foliage leaves*, and for this reason are often called bifoliar spurs. The foliage leaves, which are markedly xerophytic (p. 84), remain on the tree for three years or longer, until the dwarf shoots carrying them are shed. The younger

FIG. 345.—The Scots Pine. 1, branch with male (*a*) and female (*b*, *c*) cones; *c*, cone ($\times \frac{3}{5}$). 2, two views of a stamen ($\times 2$). 3, scales bearing two ovules ($\times 2$). 4, scale with two seeds (*a*); wing (*b*); seed (*c*). 5, seed in longitudinal section ($\times 1\frac{1}{2}$). (After Strasburger.)

branches are thus clothed with foliage at all seasons, and the tree is evergreen.

The pine is monoecious. The **male flowers** are egg-shaped, about a quarter of an inch long, and appear in spring in close clusters (Fig. 345, *1*, *a*) at the bases of some of the new shoots of unlimited growth—plainly taking the places of dwarf shoots in this region. A male flower (Fig. 346, *A*) consists merely of an elongated fleshy axis (thalamus), bearing perhaps 70 or more stamens arranged spirally; of calyx or corolla there is no trace. The stamens are not very like those of any angiosperm: each is simply a scale with two pollen sacs on its lower surface. The sacs liberate their contained pollen in May; the axis of the flower lengthens so that the stamens are separated, and the abundant pollen is shed. The pollen grains are very fine and dry, and extremely buoyant, and the wind scatters them in clouds of yellow dust.

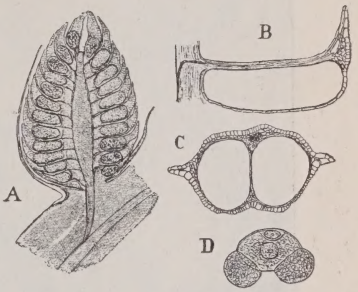


FIG. 346.—Pine. *A*, longitudinal section of a ripe male flower (× 5); *B*, longitudinal section of a single stamen (× 10); *C*, transverse section of a stamen (× 14); *D*, ripe pollen grain (× 200). (After Strasburger.)

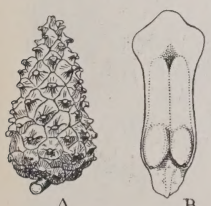


FIG. 347.—*A*, mature cone of Scots Pine (× ½). *B*, a single scale of the cone, seen from above, showing the two ovules, together with the outlines of the "wings" which separate with the ripe seeds. Enlarged. (After Le Maout.)

The **female flowers** at this time are small green and crimson **cones** close to the ends of the branches (Fig. 345, *1*, *b*). In fact, each is a modified shoot of unlimited growth, and replaces one of the buds which produce these shoots. The flower has no perianth, but consists only of a central axis or thalamus bearing spirally thick, scale-like carpels. On the upper surface of each carpel, near the axis, is a pair of ovules. The young cones are erect, and when they are ready for pollination, in May, the axis elongates, causing the scales to separate slightly, so

that the wind-borne pollen grains enter through the chinks between them, and come directly in contact with the ovules. The scales close again after pollination, and the cone hangs down

FIG. 348.—Larches, winter. *Photo. Henry Irving.*

(Fig. 345, *I*, *c*). Though the ovules receive the pollen in May, the actual union or fertilisation does not take place until June of the following year. The seeds become mature two years after fertilisation. When they are ripe each bears a thin wing, which has split off from the upper surface of the scale (Figs. 345, 347). The scales now separate, and the winged seeds are

gradually shaken out as the branch sways in the wind, and are thus distributed. When all the seeds have fallen, the empty cones drop off the tree.

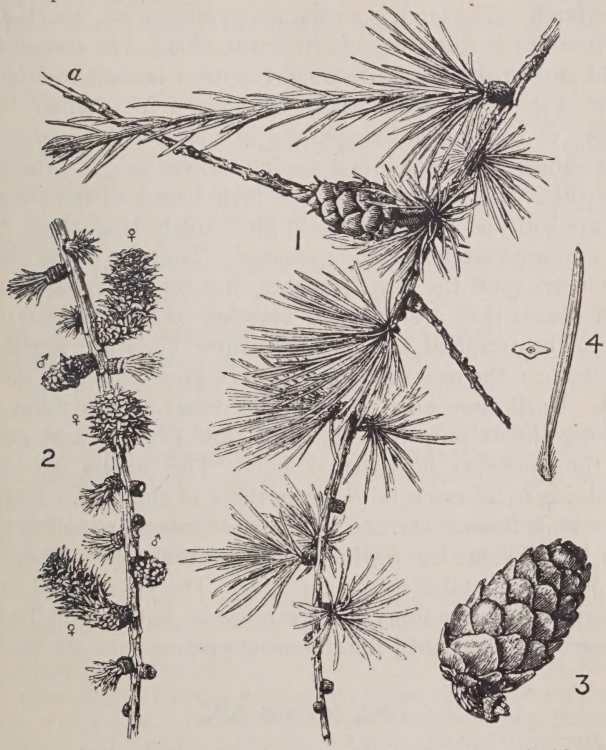


FIG. 349.—Larch. 1, twig with long and short branches, and with a cone continuing as a branch at *a*; 2, twig with staminate (♂) and pistillate (♀) flowers; 3, ripe cone; 4, leaf, entire, and cut across. (× 1.) (After Willkomm.)

Owing to the length of time necessary for the ripening of the seeds, cones of various ages may be found on the tree all the year round.

The ripe **seed** of the pine contains an embryo embedded in endosperm, which, however, is not formed in the same manner as the endosperm of dicotyledonous and monocotyledonous seeds (p. 348). The embryo has about 12 cotyledons which,

on germination of the seed, first absorb the endosperm and are then pulled out of the seed-coat and brought above ground by elongation of the hypocotyl.

The larch.—The larch is a common gymnosperm, which differs in several interesting respects from the pine. The tree is deep-rooted and grows tall and straight, with a conical monopodial crown (Fig. 348); it is easily recognised in summer by its festoons of light-green foliage, and in winter by the cones and dwarf shoots which stud its drooping leafless twigs. The **foliage leaves** (Fig. 349, *4*) are about one inch long and narrow; but they are soft and transpire much more freely than those of the pine, and are therefore *shed in autumn*. They are borne directly and singly upon the long branches, but on the thick rounded dwarf shoots they are crowded together to form characteristic tufts. The terminal and axillary winter buds are egg-shaped or globular; the new shoots and leaves grow out from them in April. Until they bear flowers, the dwarf shoots differ from the long shoots only in their very slow growth, and may at any time develop into long shoots. The **flowers** are cones, resembling in all essential respects those of the pine. Both the yellow male flowers and the red female flowers are solitary, and borne by the same tree at the ends of dwarf shoots. They open, and pollination takes place, in May. The egg-shaped female cones ripen in the summer of the same year, but the small winged seeds are not shed until the following year.

EXERCISES XX.

1. Give an account of the main features by which you would recognise a horse-chestnut tree in the winter time. What changes take place in the twigs of this tree in the spring? (J.M.B. Sch. Cert.)

2. How would you determine the age of a branch of a horse-chestnut tree? Describe the summer and winter twigs respectively of the lime. (J.M.B. Sch. Cert.)

3. How would you distinguish a horse-chestnut from a sycamore (*a*) in June, (*b*) in December at close quarters, and also at a distance of about 20 yards? (J.M.B. Sch. Cert. and Matric.)

4. Describe briefly the main features of and identify specimen D. Make a drawing of the end inch of the twig and its appendages, labelling the parts. [D = Lime twig of current year with fruits and uninjured apex.] (J.M.B. Sch. Cert.)

5. Draw a winter twig of a horse-chestnut and an elm. Make further diagrams which would show the branching of the trees during the following summer. What influences would affect the growth of the branches ? (Prel. Cert.)

6. How would you recognise, in winter and in summer, the following trees : oak, ash, beech ? (N.F.U.)

7. Give a general description of *either* a beech tree *or* an ash tree at various seasons, making sketches of any details you like. (Prel. Cert.)

8. Describe as exactly as possible the changes in the appearance of *either* (i) a beech *or* (ii) an ash tree, from the beginning of the unfolding of the buds in the spring to the shedding of the fruits. What do you consider the most important condition leading to the opening of the buds ? (J.M.B. Matric.)

9. Give an account of twigs of the lime and beech in the flowering and fruiting condition. (J.M.B. Sch. Cert. and Matric.)

10. If you were given twigs of sycamore, beech and lime in their summer condition, by what characters would you identify them and distinguish them from each other ? (J.M.B. Matric.)

11. Can you cite from your own observation any two common English deciduous trees in which the withered leaves usually remain on the young trees throughout the winter although they fall off the older trees in autumn ? Contrast the advantages and disadvantages of the deciduous and evergreen habits for trees growing in England. (J.M.B. Hr. Sch. Cert.)

12. Describe carefully the appearance of a beech in December, and the changes it undergoes in the next twelve months. (J.M.B. Matric.)

13. Make a series of accurately labelled drawings illustrating the structure of the fruit in the specimen provided. Describe carefully the changes which have taken place since pollination. [Young fruits of hazel.] (J.M.B. Matric.)

14. Give a description of the structure of the flowers of the willow *or* the ash. Describe how pollination is brought about, and indicate the method by which the seeds are dispersed. (J.M.B. Matric.)

15. Select any two of the following trees, and describe the flower and fruit of the two selected, with careful reference to any adaptations for ensuring pollination and the distribution of the fruits or seeds : elm, willow, ash, oak. (N.F.U.)

16. Compare the catkins and fruits of the willow and hazel, with special reference to the methods of pollination and seed dispersal. (Prel. Cert.)

17. Describe the connection between branch and leaf arrangement in plants. Illustrate your answer by reference to the mode of branching of the oak, ash and Scots pine. (Cert.)

18. Explain as far as you can in what way pines are adapted to live (*a*) on dry soil, (*b*) in cold and windy places. (O.S.)

19. Draw up a table which would enable a beginner in the study of botany to identify the following from twigs taken from trees in spring (say at the end of April) : horse-chestnut, oak, sycamore, larch, pine. Give sketches. (Cert.)

20. Explain the botanical significance of the setting of larch trees close together in a plantation. (C.S. part question.)

21. Describe the winter state of any *four* of the following plants : Lily of the valley, crocus, turnip, beech, holm oak, larch, hazel. What is the advantage in each case of any change from its summer state ?

22. Give a clear description of the reproductive organs of a pine tree, so far as they can be made out by the help of a lens. What are the chief differences between these and the corresponding organs in a buttercup ? (O.S.)

23. Give a careful account of the structure of the female cone of the Scots pine, and point out in what respects it differs from the flower of an angiosperm.

24. Describe fully the structure of the ripe *female* cone and the method of seed-dispersal in the Scots pine.

25. By what vegetative and floral distinctions are monocotyledons marked off from dicotyledons, and both from gymnosperms ? (L.L.A.)

26. Give a brief description of the twigs of one deciduous and one evergreen tree in summer. Point out the principal differences between them, and say what you think may be the meaning of these differences. (J.M.B. Matric.)

27. What evergreen trees have you seen growing in this country, and in what situations ? What advantages and disadvantages of the evergreen habit can you suggest, as contrasted with the deciduous habit ? (J.M.B. Hr. Sch. Cert.)

28. Describe any common tree that you have carefully observed throughout the year. How far is it true to say that a tree is always young ? (N.F.U.)

29. Describe the characteristic features in spring of any two trees whose development you have watched. (J.M.B. Jun. Cert.)

30. Describe, with drawings, the features by which you would recognise from a distance of about thirty yards any *three* trees in winter. (C.J).

31. Describe with the aid of drawings the vegetative features of any *two* trees of different habit. (C.S.)

32. Make use of external features like bark, branches, and buds to illustrate how you would distinguish any four common trees in winter. (Prel. Cert.)

33. Give the distinguishing features both in summer and winter of three British trees. On what soils are they found ? (J.M.B. Hr. Sch. Cert.)

CHAPTER XXI.

SOME COMMON FLOWERLESS PLANTS.

55. THE MALE-FERN.

PRACTICAL.

1. Habit of growth.—In summer dig up a plant of the common male-fern (Fig. 350) and wash the soil from the roots. Make out the short, stumpy, creeping *stem*, covered with the hairy bases of old leaves; the slender matted *roots* springing from the leaf-bases; the large, compound *leaves* or *fronds* of the current year, and the coiled young leaves which have not yet expanded.

2. The stem.—Remove the large leaves, leaf-bases, and roots from the stem, and examine it. Notice how the youngest leaves are grouped round the apex of the stem. Cut across the other end of the stem, and notice the cut ends of the *conducting strands* embedded in a softer *ground-tissue*. Draw. Test the cut surface with iodine solution. Cut the stem in halves lengthwise, make a drawing to show the arrangement of the young leaves round the apex, and the connection of the vascular strands of stem and leaves. Soak one half of the stem in dilute (10 %) hydrochloric acid until the ground-tissue is soft, and then with a blunt instrument carefully scrape away the ground-tissue to see how the harder conducting strands are connected together. Draw. If you spoil this half, try again on the other.

3. The leaves.—Make a drawing of part of one of the expanded leaves, showing the leaflets and their segments. Notice the brown hairs clothing the leaf-stalk and the midrib.

Notice the crozier-like coiling of the young fronds, and make out that when they uncoil, the inside of the coil becomes the upper surface of the leaf.

4. The reproductive organs.—In autumn, examine the lower surface of full-grown fronds, and notice the brown rounded patches

(*sori*), each covered with a scale. Draw a leaflet to show their arrangement. Dry some leaves bearing sori and shake them over a sheet of paper. Collect the brown dust which falls from the sori; it consists of minute grains called *spores*.

5. The prothallus.—Boil small pieces of tile (*e.g.* broken flower pot) to sterilise them. Shake some fern spores thinly on the surface of each and stand it in a saucer of water so that its lower part remains wet. Cover with a tumbler, and keep it in a fairly warm place out of direct sunshine. Notice that in a few weeks the spores have grown into small, flat, green, heart-shaped plants. Each of these is called a *prothallus*. Pick off prothalli of different ages with a needle, float them in water, and compare the various stages of growth. In old prothalli notice a young fern plant springing up from the lower surface. Observe that as these become larger, the prothalli which bear them shrivel up and die.

The daily life of a fern.—The everyday life of a fern is very similar to that of a flowering plant; for the organs by which it obtains food are—broadly speaking—of the same type. Ferns are lovers of damp and shady situations. The plant obtains solutions of mineral salts from the soil by means of its roots; and its spreading green leaves, or fronds, with the help of the sunlight, decompose the carbon dioxide of the air and build up starch and other carbonaceous compounds.

The male-fern.—As a type of the ferns we may take the common male-fern, so called, probably, because of its sturdy vigour; it has, as a matter of fact, no sex whatever. It occurs abundantly in woods and hedgerows. The **stem**, or **rhizome**, is short and stumpy; it grows obliquely upwards, and does not branch. It is covered with old leaf-bases, which are clothed with brown scales, really flattened hairs. The stem consists of a rather soft and starchy ground-tissue, in which is embedded a hollow cylindrical network of conducting strands. In a cross section these appear as a somewhat irregular ring of dots (Fig. 350, 2,). When the soft ground-tissue is carefully scraped away, the network of strands is left as a skeleton, with large diamond-shaped meshes.

The thin wiry **roots** spring from the bases of the leaf-stalks, just where these come off the stem.

The **leaves** or fronds of the male-fern arise near the growing-point (the upper end) of the stem. Leaves of almost all ages are present. Those which surround the growing-point are mere rudiments; while slightly older leaves (Fig. 350, 1, *a*) are tightly rolled up into a crozier-like coil. During their growth the coils unfold, the inside of the coil becoming the upper surface of the

FIG. 350.—The Male-Fern. 1, Illustration showing general habit ($\times \frac{1}{10}$): *a*, young leaves; 2, cross-section of stem showing conducting bundles; 3, portion of leaf: *b*, sporangia, *a*, covering scale; 4, longitudinal, and 5, cross-section, of leaf with group of sporangia: *b*, scale, *c*, sporangia; 6, a single sporangium: *c*, spring, *d*, spores.

leaf. A fully-expanded leaf is roughly triangular in shape. The erect leaf-stalk is strengthened by a cylinder of stiffening tissue just beneath the skin. It and the midrib are covered with golden-brown, scaly hairs; and the blade of the leaf is bipinnate, being divided into many distinct leaflets, which are arranged on the midrib in two rows. The leaflets are also in many cases sub-divided into separate segments, making the leaf tripinnate. The veins fork at the ends.

The spores.—On the lower surface of many of the segments of

a male-fern frond may be seen a number of small, brown, kidney-shaped scales (Fig. 350, 3, *a*). Each scale has a short stalk, and thus bears a rough resemblance to a little umbrella. Attached to the bottom of the short "handle" of the "umbrella" is a group of tiny boxes, somewhat like pill-boxes. These are shown at *b* (Fig. 350, 3), and more highly magnified at 4 and 5. The boxes are called **sporangia**, and each group of sporangia is referred to as a *sorus*. Fig. 350, 6, represents a single sporangium, more highly magnified. When ripe, each sporangium contains about fifty minute grains, which may thus be likened to the pills in the pill-boxes. These "pills" are called **spores.** Summing up thus far, we may say that the spores are formed in boxes called sporangia, which are attached by stalks to the lower surface of the frond, each sorus or group of sporangia being covered by a protective scale.

The scattering and germination of the spores.—When the spores are ripe, each sporangium (Fig. 350, 6) becomes dry, and is ultimately burst by the sudden straightening of a "spring" (*c*) —a row of cells round its edge. The force of the unbending and rebound of the spring is sufficient to jerk the spores (*d*) out of the sporangium into the air, and they may be carried for some distance by the wind before they at length reach the ground. Once there, however, each spore, under favourable conditions, begins to grow, and gives rise to a curious little plant called a **prothallus.**

The fact that a fern spore can germinate and form a new plant has led many people ignorant of botany to think of fern spores as small seeds. There could hardly be a greater mistake. A spore is a single cell, whereas a seed is a most elaborate structure (Chapter I.) composed of thousands of cells.

The prothallus.—The prothallus—the new plant which develops when a fern spore germinates—does not in the least resemble the parent fern which produced the spore. This **new generation** is a flat, filmy little plant, of the form which is generally called heart-shaped (Fig. 351). It has neither stem nor roots, but, as it contains green colouring matter like that of leaves, and as it puts out on its lower surface little hairs (*rh*) which take up mineral solutions from the soil, it is in no danger of starvation,

and is quite capable of taking care of itself and leading an independent existence.

This tiny plant (a large fern prothallus is perhaps half the size of a 3d. piece), in contrast with its parent, produces sexual organs. Some of these organs (*an*) give rise to male cells (gametes) and others (*ar*) to female gametes. The male gametes are excessively small, and can only be seen with high powers of the microscope. When they are ripe they swim about in a drop of rain or dew, as if they were little animals, and find their way to the female gametes, which they fertilise. Since in this case fertilisation depends on the presence of external water, the fern prothallus is essentially an **aquatic** plant.

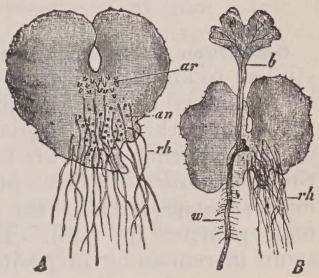


FIG. 351.—The Male-Fern. *A*, Prothallus seen from below; *an*, male organs; *ar*, female organs; *rh*, hairs. *B*, Prothallus with young fern attached to it; *b*, the first leaf; *w*, the primary root (about 5 times nat. size).

The *embryo* which results from the union of the gametes (Fig. 351, *B*) grows up into an ordinary fern plant, one being borne by each prothallus. In its young stages it is *parasitic* on the prothallus, *i.e.* it depends entirely upon the prothallus for its nutrition; but it soon develops a little leaf (*b*) and a root (*w*), and henceforth feeds itself. When the young fern is well established in independent life, the prothallus shrivels up and dies. The subsequently-formed roots of the fern are not branches of the primary root, but spring from the bases of the leaves.

Alternation of generations.—In the complete life cycle of a fern there are thus two very different generations, each of which resembles, not its parent, but its grandparent. The more highly developed generation (the ordinary fern) reproduces itself, not by the union of sex cells, but by air-borne spores—each a single cell—and is therefore called the **sporophyte**, or sporing plant. The offspring (prothallus) resulting from the germination of a spore differs from its parent by producing sex cells or gametes, and is therefore called the **gametophyte**. The union of a male gamete with a female gamete gives rise

to another sporophyte. The life history may be illustrated thus :

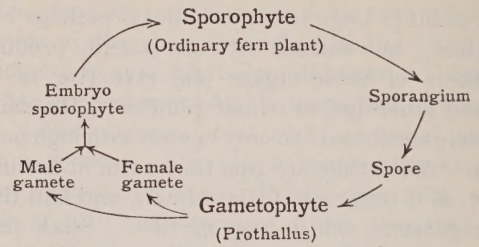


FIG. 352.—Diagram of the life-history of a Fern.

Comparison of fern and flowering plant.—It will interest the student to know that every stage in the life history of a fern can be recognised in that of a flowering plant, although it is outside the scope of this book to give the evidence in detail. The *spores* of the flowering plant are of two kinds—the *pollen grains* and the *embryo-sacs*. When a pollen grain germinates, it produces a male **gametophyte** called the *pollen tube*, which gives rise to two male gametes (p. 348). The embryo-sac differs from a fern spore in remaining in position inside the sporangium (ovule)

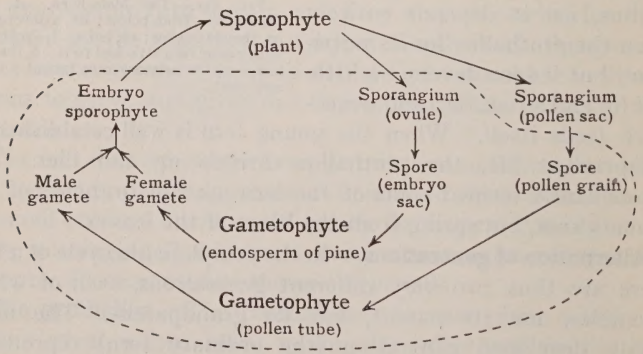


FIG. 353.—Diagram of the life-history of a Flowering Plant. The names of the parts which take a direct shape in the formation of the *seed* are enclosed in a dotted line. (Compare with Fig. 352.)

and on the parent plant. It produces a many-celled female gametophyte which in the pine is the *endosperm* and gives rise to the female gametes; but in dicotyledons and monocotyledons the female gametophyte is reduced to a few cells only (p. 348),

all of which are apparently potential female gametes. The union of a male and a female gamete results in an embryo which becomes the new **sporophyte.** In flowering plants the gametophyte is clearly very much reduced, as compared with a fern prothallus, and it never lives an independent life, but is entirely "parasitic" on the sporophyte. The life-history of the flowering plant is shown diagrammatically in Fig. 353.

56. A COMMON MOSS.

PRACTICAL.

1. The gametophyte.—Separate a single plant from a tuft of the common moss (*Funaria*) which grows, almost everywhere, on sandy ground and on walls. Notice the small *stem* (perhaps ½ inch high), thickly covered with small, simple green *leaves*. The plant is fixed in the soil by a tuft of fine hairs.

2. The sporophyte.—On some of the plants notice a thin stalk springing from the top of the stem; and on the end of the stalk an ovoid *capsule* or spore-box. In cases where the stalk is not yet full-grown, notice that the capsule is covered by a conical *hood*, somewhat like a candle-extinguisher.

3. Germination of the spores.—Select a plant bearing a ripe capsule, and warm it gently before a fire—holding it on a sheet of paper—to dry it. Examine the mouth of the capsule with a lens, and try to see the teeth which surround the opening. Then shake the capsule over moist soil in a small flower-pot to scatter the *spores*; cover with a sheet of glass and keep in a warm room. In a few days notice that the soil is covered with fine green threads. Ultimately new moss plants will grow from these.

The life-history of a moss.—A moss plant appears at first sight to be very similar in its general features to one of the higher plants; for it has a little stem, bearing flattened green "leaves" which build up carbonaceous food in the usual way. It has no true roots, but fine hairs from the base of the stem penetrate the soil and do the work of roots by taking up solutions of mineral salts. It is all the more remarkable, therefore, to find from its method of reproduction that the moss "plant" belongs to the generation (the **gametophyte**) corresponding to the prothallus stage of a fern's life-history, and not to the

leafy, sporing generation, which it somewhat resembles superficially.

The sexual organs of a moss are formed at the tip of the stem. They are essentially of the same type as those which a fern prothallus bears, and here also the tiny male gametes gain access to the female gametes by swimming through a drop of rain or dew. The result of fertilisation is an embryo, but the **sporophyte** into which it develops is not a separate plant with stem and leaves, but a stalked spore-case only.

FIG. 354.—A Moss. *A*, a plant with spore-case still covered by hood (*c*). (× 1.) *B*, a plant with ripe spore-case (*k*); *s*, stalk; *d*, lid; *rh*, hairs. (× 1.) *C*, mature spore-case with lid (*d*) removed; *p*, fringe of teeth. (× 3.) (After Strasburger.)

In a tuft of any common moss several stages of development of the spore-cases may usually be seen (Fig. 354). In *A*, the spore-case of the sporophyte is still covered by a conical hood (*c*). In *B*, its stalk (*s*) has grown much longer, and the hood has dropped off. The spore-case or capsule (*k*) is now seen to be a pear-shaped body, closed by the lid (*d*). When the spores are ripe, the lid becomes detached. The mouth of the nodding capsule is still blocked, however, by a number of teeth (Fig. 354, *C*, *p*) which remain close together in damp weather. In dry weather the teeth separate, and the spores fall out when the capsule is shaken by the wind. When a moss spore falls in a favourable situation it germinates (Fig. 355, *A*) to form a fine, branching network of green threads (*B*), from which new moss plants arise as vegetative buds (*kn*).

Vegetative propagation also takes place freely by the formation of numerous erect branches from the underground hairs, giving rise to the familiar tufted habit.

It will be noticed that in the moss, unlike the fern, the gametophyte generation is more elaborate, and better equipped for vegetative growth, than the sporophyte, which is a mere stalked spore-case, always more or less dependent on its parent (Fig. 354) and dying down as soon as its work of scattering the spores is accomplished. It is evident also that in both moss and fern the sporophyte is specially adapted to an aerial life, and therefore able, by wind-borne spores, to scatter its offspring far and wide.

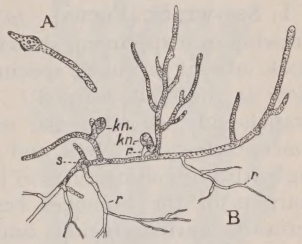


FIG. 355.—*A*, germinating moss spore. *B*, network of green threads resulting from germination of moss spore; *s*, spore; *r*, hairs penetrating soil; *kn*, buds. (Magnified.) (After Strasburger.)

The conquest of the land.—It is very significant that both ferns and mosses, though so much at home on land, have an essentially aquatic generation in their life history, and there is no doubt that they, and all other land plants, are descended from ancestors which lived in water. Successful invasion of the land must have depended not only on some means of dispersal through the air, but also on the plant's ability to set aside one portion for absorption of mineral solutions from the soil, while another portion (exposed to the light and air) was concerned with photosynthesis. In mosses this differentiation into underground and aerial regions with distinct functions has been carried out with moderate success by the *gametophyte* generation, while the sporophyte does little beyond scattering the spores. Conversely, in the ferns and their relatives, and in the flowering plants, it is the *sporophyte* generation which has taken over the work of food-making and growth, in which it has attained a high degree of efficiency and complexity—with true roots, a system of conducting vessels and aerating channels, and a photosynthetic apparatus protected by a cuticle and stomata from the risk of excessive evaporation: features practically unknown in any gametophyte. The gametophyte, on the contrary, has become very simple in ferns, while remaining semi-aquatic. In the flowering plant, finally, the gametophyte has been reduced to little more than the gametes themselves, which no longer depend upon liquid water for their union (p. 348). In short, the higher plants owe their dominant position to the greater perfection which the sporophyte has reached in the course of ages.

57. A BROWN SEAWEED.*

PRACTICAL.

1. Sea-wrack (Fucus). (*a*) *General features.*—Make an outline drawing of a specimen, showing the *disc* or holdfast, the cord-like stalk (absent in young specimens), and the method of branching. How is the stalk formed ? Draw in detail one of the swollen branch-ends, showing the wart-like *conceptacles.* Examine the conceptacles with a lens, and make out that each has a little opening with protruding tufts of hairs. Look for similar hairs on the margins of the branches further back. Cut a fresh specimen across in various regions and study the different tissues with a lens. Notice the abundance of slimy mucilage ; suggest its use at low tide in hot weather. Dip a branch into hot water and observe the change of colour.

(*b*) *Different species of Fucus.*—Distinguish between *F. vesiculosus* (bladder wrack), with air bladders (how do you suppose they benefit the plant ?), *F. serratus,* with serrate margin, and *F. platycarpus,* with entire margin and thinner branch ends.

(*c*) *Reproduction.*—Hang up to dry fresh mature *Fucus* plants which have been in sea-water † for six hours or more. Notice the drops of mucilage which ooze from the conceptacles. [With *F. vesiculosus* or *F. serratus* the mucilage from male plants is reddish-yellow ; from female plants it is greenish. *F. platycarpus* has both male and female organs in the same conceptacle.] Mount some of the mucilage in sea-water, and examine with the microscope. If the plant is *F. vesiculosus* or *F. serratus* mix the two mucilages, mount in sea-water,† and examine with the microscope.

A common brown seaweed.—Between tide-levels on our shores various species of sea-wrack (*Fucus*) are abundant. The flexible cord-like stalk is attached at one end by a disc to a rock, and at the other end is continued as a midrib into a broader portion (frond) with thin margins, which forks repeatedly in one plane. The plant-body as a whole is described as a **thallus,** since its parts are not differentiated into root, stem and leaves,

* Can be obtained (fresh or preserved) by post from The Marine Biological Association, Plymouth.

† A 3 per cent. solution of Tidman's sea salt may be used instead.

and cannot even be considered modified forms of these. (Compare the prothallus of a fern.) The whole plant contains an abundance of mucilage, which saves it from becoming dangerously dry at low tide.

The terminal inch or so of many of the flattened branches is slimy, swollen, and marked by a multitude of little wart-like projections, called **conceptacles.** When these are examined with a lens, each is seen to have a tiny hole at its summit, from which a tuft of fine hairs protrudes. Similar tufts are often found growing in small pores on other parts of the thallus.

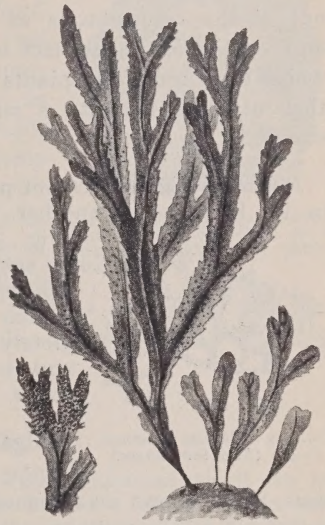


FIG. 356.—*Fucus serratus.* To the left, the end of an older branch bearing conceptacles. (× ½.) (After Strasburger.)

Nutrition and growth.—A piece of the thallus dipped in hot water turns green, revealing the presence of **chlorophyll**, the colour of which is normally masked by brown pigment. In the light the plant is therefore capable of photosynthesis, utilising the carbon dioxide dissolved in the sea-water. Their peculiar colour seems to enable the brown seaweeds to live in water too deep to transmit the light necessary for pure green seaweeds. It is supposed that the necessary mineral salts are absorbed from the sea-water by the tufts of hairs referred to above. The food made in the thin margins of the branches is distributed, by elongated cells of the midrib, to the growing points at the ends of the flattened branches. The plant is often propagated vegetatively by pieces torn off by the waves and washed to other places where they can become attached to rocks.

Reproduction.—*Fucus* shows no alternation of generations, its reproduction being exclusively sexual. In *F. vesiculosus* and *F. serratus*, minute male gametes are formed in the conceptacles of some plants, and larger female gametes in the conceptacles

of others. In *F. platycarpus* both kinds of gametes occur in the same conceptacle. When the plant is exposed by the receding tide, the gametes with a drop of mucilage are squeezed out of the conceptacles as the surrounding tissues contract, and fertilisation takes place on the surface, or in the sea-water, when once more the plants are covered. The fertilised egg then attaches itself to a support and develops into a new seaweed.

Although *Fucus* does not pass through an asexual generation in its life-history, another brown seaweed, called *Dictyota* (Fig. 357), has a regular alternation of sexual (gametophyte) and asexual (sporophyte) generations which are of similar appearance. As the plant is completely aquatic, both its asexual spores and its fertilised eggs are dispersed by water.

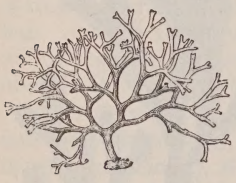


FIG. 357.—*Dictyota dichotoma.* ($\times \frac{1}{3}$.) (After Strasburger.)

Algae and fungi.—*Fucus* and *Dictyota* belong to a great group of plants called **algae**, which shows an enormous range of size and complexity, including microscopic one-celled plants at one extreme, filamentous plants consisting of a single line of cells, globular colonies of cells, and so forth, up to huge and complicated seaweeds. They are typically aquatic; they abound not only in the sea, but also in rivers and ponds, and they exist in countless millions as the green powdery deposit to be seen on damp walls (p. 89). Possessing chlorophyll (which in the brown and red seaweeds is masked by other colouring matter), they obtain their food in essentially the same manner as the higher green plants, which include the flowering plants and the groups to which ferns and mosses belong.

The **fungi** include such plants as mushrooms, puffballs, mildews, moulds, smuts, rust of wheat, etc., canker of trees, dry rot, and the single cells of which yeast is seen to consist when examined by the microscope. Like the algae, they are *thallophytes*, that is, they are devoid of parts corresponding *in structure* to roots, stems and leaves, though many of them have elaborately specialised organs of reproduction. Their outstanding

peculiarity is an entire **lack of chlorophyll**, and this compels them without exception to be either parasites or saprophytes (p. 226).

The **lichens** (many of which form coloured crusts on walls and tree trunks, while others are so complicated as to be known popularly as mosses) afford a remarkable example of *symbiosis*, that is, a partnership between very different organisms for mutual benefit. Each lichen is composed partly of a fungus and partly of an alga, in very intimate physiological association, the first absorbing mineral solutions, and the second—in virtue of its chlorophyll—making the carbonaceous foods needed by both.

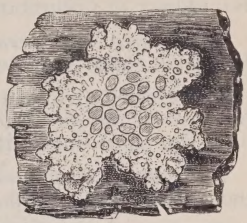


FIG. 358.—*Xanthoria parietina* (a common yellow lichen) on a piece of bark. (Nat. size.) (After Strasburger.)

EXERCISES XXI.

1. Describe, as fully as you can, the differences which can be seen by the naked eye between the leaf of a fern and that of a flowering plant. In what way do the functions of the two leaves differ ? (O.S.)

2. Give an account of the mode of reproduction of a fern plant, with a careful description of its reproductive organs. What sort of plants do the spores grow into ? (J.M.B. Sch. Cert.)

3. Give a brief account of the structure, mode of life, and reproduction of the prothallus of a fern. What kind of offspring does it produce ?
Point out how it carries on the ordinary functions connected with nutrition in plants. (J.M.B. Matric.)

4. Describe the life-history of a typical fern. Show how the two main stages in the life-cycle differ in regard to :
(*a*) the external form of the plant ;
(*b*) the mode of life. (J.M.B. Sch. Cert.)

5. Make careful enlarged drawings to illustrate the external features and construction, so far as is possible after dissection and examination with a lens, of specimens A and B. Label your drawings fully, and say as nearly as you can what the specimens are.
[A = A cluster of hawthorn fruits—fresh ; B = A piece of fertile maidenhair fern frond—3 or 4 pinnae.] (J.M.B. Sch. Cert.

6. Describe briefly the specimens A, B, and C, and point out carefully the features of botanical interest which they exhibit.
[A = Fern (*Asplenium bulbiferum*) with sori and young plants. B = Flower of Columbine. C = Twig of lime.] (C.H.L.)

7. Compare *in general terms* the structure and life-history of a fern with those of a flowering plant.

8. Describe, without giving microscopic details, the general features of the structure and life-history of a moss plant. How does the plant obtain its food materials? (J.M.B. Matric.)

9. Compare *in general terms* the structure and life-history of a moss with those of a flowering plant. (C.H.L.)

10. Compare and contrast the vegetative body of *either* a moss *or* a liverwort with that of a green flowering plant, both as regards external form and mode of nutrition
(J.M.B. Sch. Cert. and Matric.)

11. Describe the mode of life of a brown seaweed, and compare it with that of a green plant. (J.M.B. Hr. Sch. Cert.)

12. Describe the mode of growth of *Fucus*, with special reference to the nature and formation of the stem-like lower part of the thallus. Give an account of the conditions of life of this plant and its mode of nutrition. (J.M.B. Matric.)

13. In what respects does the vegetative body of a brown seaweed differ from that of a green flowering plant? State clearly how brown seaweeds obtain (*a*) mineral substances, (*b*) organic food materials. (J.M.B. Sch. Cert. and Matric.)

14. Write a short essay on sexual reproduction in plants.
(J.M.B. Matric.)

15. Compare and contrast the life-history of a fern with that of a moss.

16. What is meant by alternation of generations? Contrast the manner of life of the two generations of a fern.

CHAPTER XXII.

EVOLUTION AND HEREDITY.

What is a species ?—The possibility of distinguishing between different kinds of buttercup, *i.e.* different species of the genus *Ranunculus*, was clearly shown in Chapter XIX. (p. 371). We saw that the bitter buttercups (*R. acris*) have characters which never occur together except in this species, and therefore serve to identify it. The goldilocks buttercups (*R. auricomus*) have a different set of characters, the lesser celandines (*R. ficaria*) have a third set, and so on. Similar remarks could, as we know, be made of the different species of any other genus. A species is evidently a sharply-defined group. It is a kind of plant or animal different in some *constant* way or ways from every other kind of plant or animal. It "breeds true"; the seeds of a bitter buttercup never grow into lesser celandines; seeds of primrose (*Primula vulgaris*) never grow into cowslips (*P. veris*).

Hybrids.—It is nevertheless a fact that primrose ovules fertilised by cowslip pollen produce seeds which in favourable circumstances will grow into a kind of primula plant intermediate in characters between its parents. But this "hybrid" primula is not a new species, for it is incapable of producing seeds; in other words, it is sterile. Closely allied species of many other genera (*e.g.* species of willow, bramble, etc.) often form hybrids among themselves, but either these hybrids are sterile or they do not "breed true." If it were not for the **sterility of hybrids** *of different species*, the distinctions between the species would have been obliterated long ago by free inter-breeding. We have thus a means of knowing whether we are dealing with two

species, or merely with two varieties of one species.* For example, some garden peas are tall while others are dwarf, and a " pure strain " of each can be got which will breed true. Tall and dwarf peas, however, are not different species ; for when flowers of the tall plants are fertilised by pollen from the dwarf plants, or *vice versa*, the resulting seeds grow into plants as fertile as their parents. It is clear that tall and dwarf garden peas are only different *varieties* of one species.

Evolution.—It was not until the 19th century that biologists as a whole showed any keen interest in the question, How did the differences between species arise ? Until then, the doctrine that each species had been separately created with its present characters was generally accepted. Thus it was supposed that the ancestors of the goldilocks buttercups of to-day had always been goldilocks buttercups, and that all the lesser celandines' ancestors had been lesser celandines, which from the first were as different from goldilocks buttercups as they are now.

From the early days of science, however, certain enlightened minds had been impressed with the evidence—which became more and more convincing as the knowledge of plants and animals increased—that the similarities of structure between living things were, in general, due to an actual " blood relationship " between them, and that, with certain exceptions (p. 370), the closeness of the resemblance depended on the closeness of the relationship. Thus it came to be assumed that the various species of buttercup are so much alike, because they are all descended from the same ancestor—some long-extinct species having the essential characters of the buttercup genus, but not quite like any modern species. Similarly the conviction grew that all the genera of the family Ranunculaceae (*Ranunculus*, *Clematis*, *Anemone* and the rest) must have descended from a still earlier ancestor which, if we could examine it, we should classify in the family Ranunculaceae, though we should not be able to include it in any genus now living. In the same way it is believed that the buttercup family, the water-lily family, and the barberry family (which botanists group together in one " order ") have so much in common because, still

* Some biologists do not accept this criterion as decisive.

further back in time, they sprang from one and the same stock. Extending and amplifying this idea, which is now widely held, we could express the relationships of plants (if we knew them fully) diagrammatically by a great genealogical tree, with a different living species as the terminal bud of every twig. The construction of such a diagram is the ideal classification at which botanists have long aimed.

This, then, is the **theory of evolution**: that *every species has arisen by descent with modification from a pre-existing species.* It is supported by a mass of evidence which to an impartial mind is conclusive—evidence derived from the structure of plants and of animals, from their distribution over the earth, from the remains of the life forms of past ages which are still preserved in the rocks, and from the stages through which living things pass in their early development. In each of these branches—in morphology, geographical distribution, palaeontology and embryology—of botany and equally of zoology, we meet an array of facts which are perfectly easy to understand in the light of the theory of evolution, but are quite inexplicable on any other supposition. We cannot see evolution taking place; the process must be so inconceivably slow as to be inappreciable within the history of civilised man. Though the evidence for evolution is confessedly circumstantial, it is so complete as to leave no room for doubt.

The origin of species.—The *cause* of the modifications which must have taken place in the origin of one species from another is, however, still undiscovered, and until this is known we cannot be said to understand *how* evolution has come about. The solution of this great problem is evidently to be sought in the study of (1) Heredity, that is, the transmission of qualities from parent to offspring; and (2) Variation, the manner in which offspring differ from their parents and from each other.

Lamarck (1774-1829) offered the first plausible explanation of the origin of species. He pointed out the great modifications produced in plants and animals by the conditions under which they grow and live (we have studied cases of such modifications in Chapter XIV.), and he suggested that the new characters thus acquired are transmitted by heredity to succeeding

generations and so become fixed in the race, new species being thus formed. The flaw in this theory is that, in spite of the closest search, there is no clear proof that characters acquired during the lifetime of a parent have ever been transmitted to offspring. We know, of course, that if, of two brothers of similar constitution, one becomes a blacksmith and the other a clerk, the first will acquire greater strength of arm than the second; but the blacksmith's children, unless they also receive special training, are not likely to have stronger arms than the clerk's children. Nor would the career of blacksmith for generation after generation be more likely than any other calling, however sedentary, to produce a family whose children were born with strong arms. A gorse plant grown in moist soil produces flattened leaves, but its seeds grown in dry soil develop into plants with leaves of the usual needle shape.

Natural selection.—The greatest contribution to the study of evolution was made by **Charles Darwin**, who in 1858—at the same time as Alfred Russel Wallace—brought forward the theory of *the origin of species by natural selection.* It was well known that new varieties of domestic animals (*e.g.* cattle, dogs, pigeons, etc.) and cultivated plants (*e.g.* corn, turnips, mangel, cotton, etc.) had been gradually produced and perfected by man, by breeding only, in each generation, from the animals or plants possessing the desired qualities in greatest measure. During 20 years, Darwin patiently collected evidence in favour of the view that in nature also a process of selection is constantly at work among plants and animals which has the same effect as the human practice of artificial selection.

Natural selection is a necessary result of three obvious facts: (1) The number of offspring is so great,* and therefore the competition for food and other necessities of life is so keen (Fig. 359), that only a small proportion of the individuals of any particular generation of a species can survive.† (2) The

* It is stated that an average specimen of shepherd's purse produces 64,000 seeds, and an average male-fern over 50,000,000 spores in one season.

† Obviously if the association of plants or animals concerned is "closed" (p. 300), a new comer can only find room, etc., if a previous tenant dies.

competing individuals vary, no two being precisely alike; *from the first*, some are better endowed with the qualities which make for success in the environment, and only such will usually survive until they are old enough to *leave offspring*. (3) These offspring tend to inherit the qualities of their parents, including

Photo. Henry Irving.

FIG. 359.—Overcrowded seedlings of Sycamore, Beech and Hawthorn.

those which secured the latter's success, but they will inherit these qualities in varying degrees, and again only the best endowed will survive. Thus in each generation there is a process of natural selection which eliminates the "unfit."

The soundness of the argument so far is self-evident, but from this point it becomes more speculative. It seemed likely that even a small variation, if favourable, would become more pronounced in each succeeding generation, and might in time

amount to a difference great enough to constitute a new species. Even more probable did it appear that a species spreading to two different environments, in each of which it was able to get a footing, would eventually give rise to two different species by natural selection. The problem seemed still nearer solution when the English biologist Bateson pointed out in 1894 that *discontinuous* variation also was widespread, and when de Vries, a Dutch botanist, discovered that the so-called evening primrose occasionally produces, without human interference, very abnormal offspring which "breed true" when self-fertilised. These depart so far from the average of the species that they are described as "mutations."

There is evidence, however, that "fluctuations" (ordinary small deviations from the mean) are not transmitted from parent to offspring; and neither by artificial selection nor by any known spontaneous mutation have new species been produced answering to our definition (p. 481). Thus it is still unproved, though not disproved, that natural selection of variations, even mutations, has given rise to new species in the past.

It is important to notice that Darwin's theory, unlike Lamarck's, does not assume that any quality which an individual has *acquired* during its lifetime is transmitted to its offspring, but only the qualities which it has itself *inherited* from its own parents.

Mendelism.— Between 1856 and 1872 **Gregor Mendel,** an Austrian monk, made a number of experiments on lines which have since been followed up with great energy and success, and have thrown a remarkable light on the manner in which plants and animals inherit qualities from their parents. Let us first consider one of the simplest cases, that of the Andalusian fowl. Some birds of this breed are black, others are white, while the most admired are blue-grey. Dr. William Bateson, who has taken a leading part in extending Mendel's researches, found that when a black bird is crossed with a white one, the offspring is always grey. When grey birds are mated together, half of the offspring are grey, one-quarter are black, and one-quarter are white. A cross of black with black yields only black offspring; one of white with white yields only white

offspring. The white and black birds are therefore called "pure strains." These results are expressed in Fig. 360.

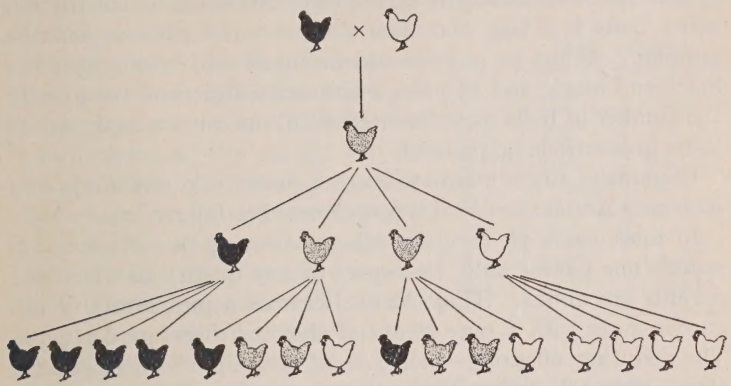


Fig. 360.—Illustrating the inheritance of feather colour in the Andalusian fowl. (From Bower, Kerr and Agar's *Lectures on Sex and Heredity*.)

The facts are explained by supposing that *all* the cells of a grey bird, whether it be male or female, contain a "factor" for whiteness and a "factor" for blackness, that is, a capacity for developing white feathers as well as a capacity for developing black feathers. (Of course, only the cells of the epidermis have an opportunity of realising this capacity.) In the formation of the sex cells or gametes, however, the factors of such pairs in the cells concerned in the process are separated; so that each gamete produced by any one grey bird has *either* a factor for whiteness (W) *or* a factor for blackness (B), but not both. The number of gametes produced by each bird is very large, and it is likely that half of them will contain W and half will contain B. Consider now the result—in mating grey birds—of the union, in pairs, of a large number of such gametes. It is clear from Fig. 361 that half the offspring will

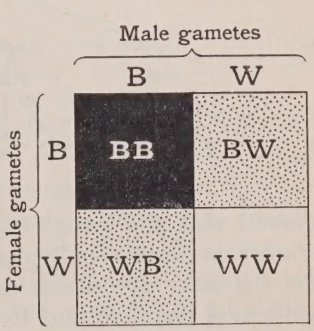


Fig. 361.

be grey (WB or BW), one fourth black (BB), and one fourth white (WW).

It is as if we thoroughly mixed (say) 100 black balls with 100 white balls in a bag, and then drew out the balls *in pairs* at random. About 50 pairs would be black and white, 25 pairs black and black, and 25 pairs white and white; and the greater the number of balls experimented with, the more exactly would these proportions be realised.

Obviously, any attempt to breed a pure strain of the admired blue-grey Andalusian fowl is fore-doomed to failure.

In most cases of cross breeding, however, the offspring resemble one parent only, in respect of any quality in which the parents are unlike. Thus, Mendel crossed a pure strain of tall garden peas with a pure strain of short or dwarf garden peas. The resulting offspring—called the "first filial" or F_1 generation—were all tall. When these were "selfed" (*i.e.* self-fertilised), however, three-fourths of the plants of the next (F_2) generation proved to be tall, and one-fourth short. This

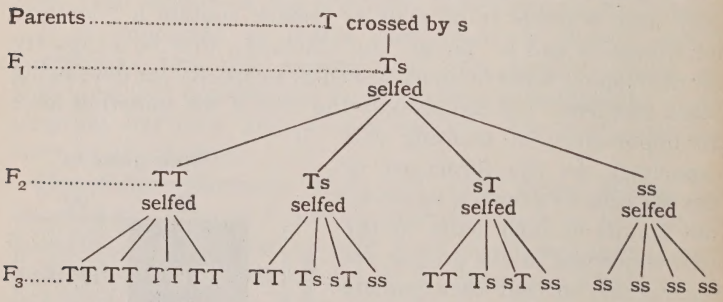


FIG. 362.

showed that the factors for tallness and shortness were both present in certain individuals of the F_1 generation, but that the character of tallness masked the character of shortness. Tallness is therefore said to be **dominant**, and shortness **recessive** in garden peas. If we represent tallness by a *capital* T (because it is dominant), and shortness by a *small* s (because it is recessive), we can illustrate the nature of the first three filial generations by the accompanying diagram (Fig. 362), which should be compared with Fig. 360.

The result of selfing the F_1 generation is shown by Fig 363.

It will be seen that the factors for tallness and shortness in garden peas are inherited in exactly the same way as the factors for blackness and whiteness in Andalusian fowls, although all the peas inheriting both tallness and shortness are tall. Evidently all short plants of the garden pea are of "pure strain"; a tall plant whose parentage we do not know may or may not be of pure strain, but the laws of Mendelian inheritance show how, if its strain be not pure, we may obtain both a strain of pure talls and a strain of pure shorts from it.

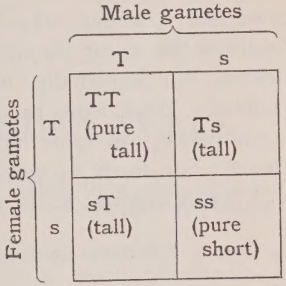


Fig. 363.

New varieties.—Large numbers of quantitative investigations have now been made of the inheritance—under different conditions of crossing—of pairs of contrasted characters, and of the various possible combinations of two or more pairs of characters. By this means pure strains have been obtained of extremely valuable new varieties, combining desirable qualities not previously found together. They are, however, varieties only, and not new species.

A simple case is the production of a variety of wheat with grains having white chaff and yielding "strong" flour (*i.e.* of good baking quality), by the crossing of parent wheats, one of which gave red chaff and strong flour, and the other white chaff and weak flour.

Mendelism and evolution.—Although Mendelism has thus proved already of enormous practical importance to breeders of plants and animals, the hopes that it would reveal the manner in which evolution has operated have not yet been realised. In conjunction with recent work on the microscopic structure of the cell nucleus—beyond the scope of this book—it has thrown remarkable light on the mechanism of variation, so that biologists now understand how it comes about that offspring of the same parents are different from each other and from their parents. But how the differences arose

which distinguish one species from another is still a mystery. As Dr. William Bateson, a leading authority on Mendelian inheritance, said recently: "The production of an indubitably sterile hybrid from completely fertile parents which have arisen under critical observation from a single common origin is the event for which we wait. Until this event is witnessed, our knowledge of evolution is incomplete in a vital respect. From time to time a record of such an observation is published, but none has yet survived criticism. Meanwhile, though our faith in evolution stands unshaken, we have no acceptable account of the origin of 'species'." *

* Toronto Lecture. See *Nature*, April 29, 1922.

APPENDIX ON CHEMICAL TESTS

Lime Water. Shake up slaked lime with water, filter, and keep the clear solution in a tightly corked bottle. Turns milky in presenc of carbon dioxide (pp. 25, 68).

Iodine Solution. Dissolve one or two crystals of potassium iodide in about 250 c.c. of water, and add iodine in small quantities until the solution is the colour of sherry. Turns starch blue or dark purple (pp. 3, 11, 15, 61, 203).

Fehling's Solution. Solution A : dissolve 44 grams of copper sulphate in 250 c.c. of water. Solution B : dissolve 88 grams of Rochelle salt in 250 c.c. of 10 per cent. solution of caustic soda. To test for a reducing sugar, mix 5 c.c. of A, 5 c.c. of B and 5 c.c. of water in a test tube and heat the mixture to boiling. The liquid should remain clear. Add a small quantity of the suspected material. A red precipitate is formed with grape sugar and maltose (pp. 15, 20, 203). Clean the test tube afterwards with dilute ammonia.

Sudan III. A concentrated solution in 70 per cent. alcohol gives a red colour with fats or oils, and a yellow colour with cutin or cork (pp. 16, 21).

Aniline Sulphate. A concentrated solution in water, made distinctly acid with sulphuric acid. Turns lignified (woody) tissues yellow (pp. 126, 127).

Phloroglucin Solution. To be obtained from dealers in microscope accessories. Should be acidified with hydrochloric acid. Turns lignified tissues magenta (pp. 16, 20).

Millon's Reagent. Dissolve mercury in 9 times its volume of strong nitric acid, and add an equal volume of water. Turns proteins brick-red (p. 17).

Comber's test for soil acidity. Shake vigorously 2 or 3 grams of soil in a test tube with a 5 per cent. solution of *potassium salicylate*, and allow to settle. An acid soil turns the solution red (p. 265).

GLOSSARY

Achene, a dry one-seeded fruit.

Acropetal succession, an order of growth (*e.g.* of leaves and rootlets) in which the youngest is nearest the tip.

Actinomorphic (flower), radially symmetrical.

Adventitious (roots, buds), arising irregularly.

Albuminous (seed), containing a store of food outside the embryo.

Androecium, the stamens collectively.

Anemophilous (flowers), pollinated by the wind.

Angiosperms, dicotyledons and monocotyledons (flowering plants with seeds enclosed in an ovary).

Anther, the pollen-bearing part of a stamen.

Apocarpous (gynaecium), consisting of separate carpels.

Aril, any structure formed on an ovule after fertilisation.

Axil, the angle upper between a stem and a leaf.

Biparous, two-branched.

Bract, a leaf in the axil of which a flower arises.

Bulb, an underground bud, some of the leaves of which are swollen with stored food.

Carpel, a floral leaf bearing ovules.

Callus, new tissue arising as the result of injury.

Cambium, actively dividing tissue between the xylem and phloem of stems and roots of most dicotyledons and gymnosperms.

Capitulum, an inflorescence of sessile flowers on a flattened receptacle.

Chlorophyll, the green colouring matter of leaves and herbaceous stems.

Chlorosis, a pale yellow condition caused by lack of iron.

Cladode, a leaf-like branch.

Cleistogamic (flower), not opening, but self-fertilised.

Connective, the part between the pollen lobes of an anther.

Corm, the swollen base of a previously erect stem.

Corolla, the petals collectively.

Corona, a tube-like outgrowth of the perianth.

Cortex, tissue between epidermis and central cylinder.

Corymb, a flat-topped or dome-shaped inflorescence with alternate pedicels.

Cotyledons, the first leaves borne by an embryo plant.

Cuticle, a thin external covering of corky nature.

Deciduous (plant), shedding the leaves annually.

Definite (inflorescence), having the oldest flowers nearest the apex.

Dehiscent (fruit), self-opening.

Diadelphous (stamens), with filaments united to form two groups.

Diastase, an enzyme converting starch to sugar.

Dichasium, a two-branched definite inflorescence.

Dichogamous (flower), with anthers and stigma mature at different times.

Dicotyledons, angiospermous flowering plants having an embryo with two cotyledons.

Dioecious (plants), having some individuals male only and others female only.

Embryo, a young individual resulting from fertilisation.

Endocarp, the inner layer of the pericarp of a fruit.

Endodermis, the innermost layer of the cortex.

Endosperm, food stored outside the embryo in a seed.

Entomophilous (flowers), pollinated by insects.

Epicarp, the outer layer of the pericarp of a fruit.

Epicotyl, the part of the stem above the cotyledons of an embryo or seedling.

Epigeal (germination), with cotyledons appearing above the surface of the soil.

Epigynous (stamens and petals), inserted on the ovary.

Epipetalous (stamens), inserted on the petals.

Epiphyllous (stamens), inserted on the perianth.

Epiphyte, a plant growing on an aerial part of another plant.

Etiolation, the condition resulting from lack of light.

Exalbuminous (seed), not containing stored food outside the embryo.

Extrorse (anther), liberating pollen on its outer face.

Filament, the stalk of a stamen.

Fluctuations, small deviations from type.

Follicle, a dehiscent, many-seeded, dry fruit.

Fruit, what remains of one flower when the seeds are ripe.

Gamete, a sexual cell.

Gametophyte, the sexual generation of plants showing alternation.

Gamopetalous (corolla), with united petals.

Gamophyllous (perianth), with united perianth leaves.

Geotropism, directional growth prompted by gravitation.

Guard-cells, the pair of green cells enclosing a stoma.

Gymnosperms, flowering plants having seeds exposed on the surface of carpellary scales.

Gynaecium, the carpels collectively.

Halophyte, a plant able to tolerate much salt.

Head, see Capitulum.

Heliotropism, directional growth prompted by light.

Hermaphrodite (flower), having both stamens and carpels.

Humus, decaying organic matter in soil.

Hydathode, a water-pore on a leaf.

Hydrophyte, a plant adapted to living in water or very wet soil.

Hydrotropism, directional growth prompted by moisture.

Hypocotyl, the part of the stem below the cotyledons of an embryo or seedling.

Hypogynous (stamens and petals), attached below the gynaecium.

Indefinite (inflorescence), having the youngest flowers nearest the apex.

Inflorescence, (1) a branch-system bearing flowers; (2) the manner of arrangement of the flowers of a common branch-system.

Internode, the part of the stem between two successive nodes.

Introrse (anther), liberating pollen on its inner face.

Involucre, the group of bracts surrounding a capitulum.
Klinostat, clockwork apparatus for rotating plants slowly.
Lamina, a leaf-blade.
Latex, a coagulating fluid exuding from certain plants when wounded.
Legume, a pod, the characteristic fruit of the pea family.
Lenticel, a pore through the bark of a tree.
Liane, a woody climbing plant.
Lichen, a compound plant consisting of a fungus and an alga living in partnership.
Loam, a soil mainly composed of a mixture of clay and sand.
Marl, a calcareous loam.
Medullary rays, transverse radial spokes or plates of tissue through the wood and the bast of a stem or root.
Mesocarp, the middle region of the pericarp of a fruit.
Mesophyll, the green tissue between the upper and the lower epidermis of a leaf.
Micropyle, the channel between the integuments of an ovule, through which a pollen tube enters.
Monadelphous (stamens), cohering by the filaments to form one group.
Monocotyledons, angiospermous flowering plants having an embryo with one cotyledon.
Monoecious (plant), bearing both male and female unisexual flowers.
Monopodium, a main stem formed by the continued elongation of the original stem.
Mycorhiza, a fungus partner on the roots of another plant.
Node, the level at which a leaf, or a whorl of leaves, grows on a stem.
Nucellus, the central tissue of an ovule, including the embryo-sac.
Nucleus, a rounded body in the protoplasm of a cell, and the centre of its activities.
Nut, a one-seeded fruit with a woody pericarp.
Ovary, the part of the angiospermous gynaecium containing the ovules.
Ovule, the early (unfertilised) stage of a seed.
Palisade parenchyma, the cells of the upper part of the mesophyll of a leaf.
Panicle, a branched raceme.
Papilionaceous (flower), "butterfly shaped," as in British Leguminosae.
Pappus, the tuft of hairs representing the calyx of many Compositae.
Parasite, an organism obtaining food from another living organism.
Parenchyma, a tissue composed of cells not much longer in one direction than in another.
Pedicel, a flower stalk springing from the main stalk of an inflorescence.
Peduncle, the main flower-stalk of an inflorescence.
Perianth, the calyx and corolla collectively.
Pericarp, the part of a fruit derived from the ovary wall.
Pericycle, the layers of the central cylinder external to the vascular bundles.
Perigynous (stamens or petals) inserted on a flattened or hollowed thalamus.
Petiole, leaf-stalk.
Phloem, bast.
Photosynthesis, the plant's utilisation of the energy of light for building up foods from inorganic materials.
Phototropism, directional growth prompted by the direction of the light.

Phyllode, a flattened leaf-stalk.
Phyllotaxis, the manner of arrangement of leaves on the stem.
Piliferous layer, the external (hair-bearing) layer of a root.
Pinnate (venation), with a laterally branching midrib.
Pistil, a syncarpous or monocarpous gynaecium.
Placenta, the region (usually swollen) of a carpel which bears the ovules.
Placentation, the manner of arrangement of the ovules.
Plumule, the upper part of the embryonic stem.
Polypetalous (corolla), consisting of separate petals.
Polyphyllous (perianth), consisting of separate perianth leaves.
Polysepalous (calyx), consisting of separate sepals.
Pome, an apple-like fruit.
Potometer, an instrument for measuring the rate of absorption of water.
Prosenchyma, a tissue composed of elongated, pointed cells.
Protandrous (flower), with the stamens maturing before the stigmas.
Prothallus (of ferns, etc.), the plant of the sexual generation.
Protogynous (flower), with the stigmas maturing before the stamens.
Pulvinus, swollen motile tissue at the base of a leaf-stalk.
Raceme, an indefinite inflorescence, consisting of alternate stalked flowers on a peduncle.
Radicle, the embryonic root.
Receptacle or thalamus, the enlarged end of the flower-stalk, bearing the sepals, petals, stamens and carpels.
Rhizome, an underground stem.
Runner, an elongated prostrate branch.
Saprophyte, an organism obtaining food from a dead plant or animal.
Schizocarp, a fruit which splits into separate carpels when ripe.
Scion, a graft or bud inserted on another plant (the stock).
Sclerenchyma, hard tissue.
Scrub, bush-land.
Scutellum, the absorptive cotyledon of a grass embryo.
Shoot, a stem or stem-branch bearing leaves.
Sieve-tubes, the vessels of the bast.
Siliqua, the characteristic fruit of the Cruciferae.
Spike, an indefinite inflorescence of sessile flowers on an elongated peduncle.
Spikelet, a compound spike, enclosed in scaly bracts (glumes). The inflorescence of grasses.
Sporangium, a spore case.
Spore, a single cell giving rise to a new plant.
Sporophyte, the spore-bearing generation of plants showing alternation.
Stamens, the floral organs bearing the pollen sacs.
Staminode, an imperfect stamen not producing pollen.
Stigma, the end of a carpel, modified for reception of pollen.
Stipules, paired outgrowths of a leaf-base.
Stolon, a runner, or elongated prostrate branch.
Stoma, a pore in the epidermis.
Style, the region, often stalk-like, connecting stigma and ovary.
Sucker, a shoot arising from an underground stem or root, and appearing above ground.
Symbiosis, a mutually beneficial partnership of two organisms of different kinds.
Sympodium, a stem composed of a succession of branches.

Syncarpous (gynaecium), consisting of united carpels.
Syngenesious (stamens), cohering by the anthers.
Ternate (leaf), consisting of three leaflets.
Thalamus (floral receptacle), the enlarged end of the flower-stalk, bearing the sepals, petals, stamens and carpels.
Tissue, a group of cells of the same kind.
Transpiration, exhalation of water vapour.
Tropism, directional growth prompted by a one-sided stimulus.
Tuber, the swollen end of an underground shoot.
Turgidity (turgescence, turgor), a tense condition of cells or tissues caused by pressure of cell sap.
Umbel, an indefinite inflorescence of stalked flowers arising close together on the peduncle.
Unilocular (ovary), having only one cavity (loculus).
Uniparous cyme, a definite inflorescence of which only one side develops.
Vacuole, a drop of sap in a cell.
Vascular bundle, a strand consisting of vessels transmitting liquids through the plant.
Vegetative (functions), other than reproductive, *i.e.* concerned with nutrition and growth.
Veins, the vascular bundles of leaves.
Venation, the method of arrangement of veins.
Vernation, the manner of folding of leaves in the bud.
Vessel, a canal or duct formed by fusion or separation of cells.
Xerophyte, a drought-bearing plant.
Xylem, the woody region of a vascular bundle.
Zygomorphic (flower), bilaterally symmetrical, as contrasted with radially symmetrical (actinomorphic).

PHENOLOGICAL LIST *

WILD AND GARDEN PLANTS OF WIDE DISTRIBUTION, ARRANGED BY APPROXIMATE DATE (DAY OF YEAR) OF FLOWERING IN GREAT BRITAIN, BY J. EDMUND CLARK, SEC., ROY. MET. SOC. PHENOLOGICAL COMMITTEE.

(From *Nature*, April 25, 1925.)

	COMMON AND BOTANICAL NAMES.	DAY OF YEAR.
1.	Snowdrop (*Galanthus nivalis*)	19
2.	Winter aconite (*Eranthis hiemalis*)	20
3.	Yew (*Taxus baccata*)	30
4.	Yellow crocus (*Crocus aureus*)	33
5.	Common elm (*Ulmus campestris*)	44
6.	Hazel (*Corylus avellana*)	44
7.	Lesser celandine (*Ranunculus ficaria*)	47
8.	Coltsfoot (*Tussilago farfara*)	65
9.	Cherry, plum or purple variety (*Prunus cerasifera* or var. *P. pissardi*)	70
10.	Bracken (*Pteris aquilina*) (shows)	80
11.	Almond (*Prunus amygdalus*)	85
12.	White poplar (*Populus alba*)	85
13.	Black poplar and Lombardy poplar (*Populus nigra* and var.)	90
14*a*.	Wood anemone (*Anemone nemorosa*)	92
14*b*.	Goat willow (*Salix cuprea*)	100
15.	Blackthorn (*Prunus spinosa*)	102
16.	Flowering currant (*Ribes sanguineum*)	110
17.	Sessile oak (*Quercus robur*)	115
18.	Pedunculate oak (*Quercus pedunculata*)	115
19.	Red currant (*Ribes rubrum*)	115
20.	Garlic hedge mustard (*Alliaria officinalis*)	120
21.	Crab apple (*Pyrus malus*)	130
22.	Horse chestnut (*Aesculus hippocastanum*)	133
23.	Common lilac (*Syringa vulgaris*)	130
24.	Quince (*Cydonia vulgaris*)	135
25.	Laburnum (*Cytisus laburnum*)	138
26.	Hawthorn (*Cratægus oxyacantha*)	139
27.	Raspberry (*Rubus idæus*)	150
28.	Ox-eye daisy (*Chrysanthemum leucanthemum*)	154
29.	Elder (*Sambucus nigra*)	160
30.	Dog rose (*Rosa canina*)	163
31.	Snowberry (*Symphoricarpus racemosus*)	165
32.	Guelder rose (*Viburnum opulus*)	165
33.	Black knapweed (*Centaurea nigra*)	190
34.	Madonna lily (*Lilium candidum*)	195
35.	Greater bindweed (*Convolvulus sepium*)	198
36.	Sweet chestnut (*Castanea vesca*)	200
37.	Montbretia (*Tritoma montbretia*)	200
38.	Autumn crocus (*Colchicum autumnale*)	245
39.	Autumn Caucasian crocus (*Colchicum speciosum*)	250
40.	Ivy (*Hedera helix*)	276
41.	Winter (yellow) jasmine (*Jasminium nudiflorum*)	280
42.	Christmas rose (*Helleborus niger*)	350

* In the North of England, leaves, flowers, etc., frequently appear 2–4 weeks later than in the South.

MONTHLY CALENDAR

JANUARY.

General.—As in December.

Plants in flower.—Shepherd's purse; daisy, groundsel; snowdrop.

Christmas rose, violet, tulip, etc., can be obtained from florists.

FEBRUARY.

General.—As in December.

Plants in flower.—Winter aconite; shepherd's purse; chickweed; gorse; daisy, groundsel, coltsfoot; mistletoe; hazel; snowdrop; crocus.

Hedges are now clipped; study the effect which this treatment has upon subsequent growth.

MARCH.

General Work for Spring Months.—Study the structure of seeds, and their germination in pots, boxes and garden (Chaps. I. and II.). Make experiments on geotropism of stems and roots (Chap. XIV.). Compare plants grown from seed in sawdust with others grown in soil (p. 113). Water culture (Chap. VII.). Examine stages of development of new shoots from

bulbs, corms, rhizomes, etc. (Chap. XII.), and from the resting buds of trees (Chaps. X. and XX.), with resulting types of branching (Chap. IX.), phyllotaxis and leaf-forms (Chap. III.). Study the paths of water from soil to leaf; ligature woody stems and observe the result (Chap. IX.). Study common types of inflorescence (Chap. XVI.). Compare different species of *Ranunculus*. Study wind-pollination as illustrated by oak, beech, hazel, alder and poplar. Examine other spring flowers of prescribed families, and their methods of pollination (Chap. XIX.).

Plants in flower.—Lesser celandine, marsh marigold, hellebore, winter aconite; shepherd's purse; violet; chickweed; gorse, red clover; sloe (blackthorn); primrose; ground-ivy; speedwell; daisy, groundsel, coltsfoot, butterbur, dandelion; sheep's sorrel; mercury; mistletoe; elm; willow, poplar; hazel; alder; daffodil, snowdrop; crocus; annual meadow-grass; yew.

APRIL.

Plants in flower.—Anemone, lesser celandine, goldilocks buttercup, marsh marigold, hellebore, winter aconite; shepherd's purse, wallflower, cuckoo flower; violet; common chickweed, mouse-ear chickweed, greater stitchwort; wood sorrel; gorse, red clover; sloe (blackthorn), wild plum, pear, quince; keck, water star wort; moschatel; daisy, coltsfoot, butterbur, dandelion, groundsel; primrose; speedwell, figwort; deadnettles, ground-ivy; sheep's sorrel; elm; crowberry; mercury; mistletoe; willow, poplar; hazel; alder, birch; snowdrop, narcissus, daffodil, snowflake; broad-leaved garlic, tulip, wild hyacinth; arum; annual meadow-grass, meadow foxtail; yew.

Trees which unfold their leaf-buds.—Larch, horse chestnut, beech, elm, sycamore.

Elm **fruits** are abundant; study the method of dispersal (p. 439).

MAY.

Plants in flower.—Anemone, lesser celandine, bulbous buttercup, goldilocks buttercup, water buttercup, marsh marigold, globe flower, hellebore, columbine; wallflower, cuckoo flower, shepherd's purse, water-cress, garlic mustard, charlock; violets, pansy; common chickweed, stitchworts, mouse-ear chickweeds, pearlwort, ragged Robin, red campion; herb Robert, wood sorrel; red clover, white clover, garden pea, beans, common vetch, bush vetch, broom, gorse; sloe (blackthorn), cherry, wild plum, wild strawberry, hawthorn, rowan, white beam, service, medlar, apple, pear; water star-wort; bryony; samphire, pignut, keck, chervil; moschatel; heath bed-straw, woodruff; mouse-ear hawkweed, dandelion, thistle, groundsel, daisy; bilberry; figwort, speedwells; deadnettles, ground-ivy, bugle; scorpion grass; butterwort; primrose, cowslip, water violet, moneywort, loosestrife; sorrel, sheep's sorrel; mistletoe; crowberry; orchids; daffodil, narcissus, snowflake; iris; broad-leaved garlic, tulip, wild hyacinth, lily of the valley, star of Bethlehem; arum; *Tamus*; Canadian pondweed, water plantain; common sedge, cotton grass; slender foxtail, meadow foxtail, annual meadow-grass, wood melick-grass, perennial rye-grass; sycamore, hedge maple, horse-chestnut, holly, ash, elm, beech, oak, birch, poplars, pine.

Most **forest trees** are now in leaf. Leaves of oak, ash, and lime unfold towards the end of the month.

Hay fields are closed to prevent damage to the crop.

JUNE.

General Work for Summer Months.—Make experiments on the conditions of photosynthesis, etiolation (Chap IV.), heliotropism (Chap. XIV.), and transpiration (Chap. V.). Observe wind pollination as illustrated by familiar grasses of hayfields. Examine inflorescences, and study structure and pollination of

flowers (especially weeds) of other prescribed families. Identify, and study the adaptations to their environment (above and below ground) of the commonest plants of neighbouring woods, hedges, heaths, ponds, etc., as well as weeds of arable land, hayfields and waysides (Chap. XV.). Study the development and structure of fruits (Chap. XVIII.), and the life-histories of ferns and mosses (Chap. XXI.).

Plants in flower.—Clematis, anemone, water buttercup, lesser spearwort, common buttercups, marsh marigold, globe flower, columbine, larkspur; poppy; wallflower, cuckoo flower, shepherd's purse, watercress, hedge mustard, garlic mustard, charlock, wild radish, sea-rocket; marsh violet, sweet violet, dog violet, pansy; campions, corn cockle, ragged Robin, pink, sea purslane, common chickweed, stitchworts, pearlwort, corn spurrey, mouse-ear chickweeds; herb Robert, meadow geranium, wood sorrel; gorse, laburnum, broom, rest harrow, vetches, clovers, hop trefoil, bird's-foot trefoil, peas, beans; bramble, wild rose, agrimony, avens, meadow-sweet, wild cherry, wild strawberry, creeping cinquefoil, tormentil, hawthorn, rowan, white beam, service, medlar, crab apple; mare's tail, water milfoil, water star-wort; bryony; stone-crop; wood sanicle, hemlock, chervil, cow parsnip, carrot; honeysuckle; cleavers, woodruff; field scabious; goat's-beard, hawkweeds, sowthistle, dandelion, thistles, corn-marigold, ox-eye daisy, daisy, ragwort, groundsel, sunflower, knapweed, cornflower; bilberry; privet; convolvulus; bittersweet; foxglove, figwort, speedwells, mullein; thyme, deadnettles, sage, ground-ivy; forget-me-not, scorpion grass; butterwort; cowslip, water violet, pimpernel, loosestrife, moneywort, brookweed; plantains; dock, sorrel, sheep's sorrel; crowberry; nettles; sweet gale (bog myrtle); bird's-nest orchid; snowflake; iris; broad-leaved garlic, wild hyacinth, lily of the valley, star of Bethlehem; *Tamus*; Canadian water-weed; water plantain; pond-weeds; sedges, cotton grass, deer's grass; wheat, sweet-scented vernal grass, mat-grass, slender foxtail, meadow foxtail, Timothy grass, sea couch-grass, common couch-grass, marram grass, soft-grass, Yorkshire fog, sheep's fescue, meadow fescue, wood melick grass, wild oat, meadow-grasses,

perennial rye-grass; sycamore, hedge maple; horse-chestnut; elder; holly; pine.

Fruits of strawberry, willow, dandelion, etc., are ripe.

Haymaking begins.

JULY.

Plants in flower.—Clematis, common buttercups, spearworts, monkshood, larkspur; white water-lily, yellow water-lily; poppy; shepherd's purse, candytuft, water-cress, hedge mustard, charlock, wild radish, sea-rocket; violets, pansy; campions, corn-cockle, pink, pearlwort, sea purslane, chickweed, stitchworts, corn spurrey, mouse-ear chickweeds, night-flowering catchfly; marsh mallow; herb Robert, meadow geranium; gorse, laburnum, rest-harrow, clovers, hop trefoil, bird's-foot trefoil, vetches, peas, beans; bramble, wild rose, agrimony, meadow-sweet, avens, wild strawberry, creeping cinquefoil, tormentil; mare's-tail, water milfoil, water star-wort, water purslane; bryony; stone-crop; sundew; wood sanicle, hemlock, water dropwort, cow-parsnip, carrot, hedge-parsley, chervil, samphire; honeysuckle; cleavers, heath bed-straw; scabious; goat's beard, hawk-bit, hawk's-beard, hawkweed, sowthistle, dandelion, chicory, thistles, bur-marigold, burdock, corn marigold, ox-eye daisy, feverfew, golden-rod, groundsel, ragwort, daisy, sunflower, yarrow, knapweed, cornflower; cross-leaved heath, bell-heather, ling; bird's-nest; privet; convolvulus; bittersweet; water violet, pimpernel, loosestrife, moneywort, brookweed; speedwells, mullein, foxglove, musk, toadflax, snap-dragon, figwort; thyme, wild basil, deadnettles, sage, skull-cap, hemp nettle, wood sage, bugle, self heal; forget-me-not, scorpion grass; bladder-wort; butterwort; plantains; orache, saltwort, sea-blite; climbing polygonum, knotgrass, common dock, water dock, sorrel, sheep's sorrel; hop, nettles; sweet gale; frog-bit, Canadian water-weed; water plantain; pondweeds; bird's nest orchid; star of Bethlehem, garlic; snowflake; iris, gladiolus; duckweed; common rush; sedges, bulrush, deer's grass, cotton grass; wheat, barley, oats, sweet-scented vernal grass, slender foxtail,

Timothy grass, marram grass, soft-grass, Yorkshire fog, wavy hair-grass, wild oat, common reed, purple moor-grass, wood melick-grass, meadow-grasses, meadow fescue, sheep's fescue, hairy brome, perennial rye-grass, sea couch-grass, common couch-grass, bent, mat-grass; lime; holly; Spanish chestnut.

Fruits of gooseberry, cherry, raspberry, strawberry, and many other plants are ripe.

Ferns.—Spores of male-fern and bracken are ripe.

AUGUST.

Plants in flower.—Clematis, water buttercup, spearworts, common buttercup, monkshood; poppy; shepherd's purse, water-cress, charlock, stock, candytuft, sea-rocket; dog violet, pansy; campions, night-flowering catchfly, corn cockle, pink, pearlwort, sea purslane, chickweed, mouse-ear chickweeds, corn spurrey; marsh mallow; herb Robert, geraniums; gorse, laburnum, rest-harrow, clovers, hop trefoil, bird's-foot trefoil, vetches, peas, beans; bramble, meadow-sweet, wood avens, creeping cinquefoil, tormentil; water milfoil, water star-wort; water purslane; bryony; stonecrop; sundew; water hemlock, water dropwort, carrot, hedge parsley, fool's parsley, samphire; honeysuckle; heath bedstraw; teasel, scabious; hawkbit, hawk's-beard, hawkweed, sowthistle, dandelion, chicory, thistles, bur-marigold, burdock, knapweed, cornflower, golden-rod, groundsel, ragwort, sunflower, Michaelmas daisy, corn-marigold, ox-eye daisy, feverfew, daisy, yarrow; cross-leaved heath, bell-heather, ling; bird's-nest; convolvulus; bittersweet; pimpernel, loosestrife, moneywort, brookweed; speedwells, mullein, foxglove, toadflax, snapdragon, musk, figwort; water mint, thyme, wild basil, deadnettles, sage, skull-cap, hemp nettle, wood sage, self-heal; forget-me-not, scorpion grass; bladder-wort, butter-wort; plantains; orache, glasswort, saltwort, sea-blite; climbing polygonum, knotgrass, common dock, water dock; hop, nettles; Canadian water weed, frog-bit; pondweeds; duckweed; garlic, meadow saffron; iris, gladiolus; rushes; water plantain; common sedge, bulrush,

deer's grass, cotton-grass ; marram grass, wavy hair-grass, soft-grass, Yorkshire fog, wild oat, common reed, purple moor-grass, meadow-grasses, meadow fescue, hairy brome, perennial rye-grass, sea couch-grass, common couch-grass, bent, mat-grass ; holly.

Leaves of horse-chestnut begin to fall.

Fruits of cherry, plum, raspberry, and many other plants are ripe ; wheat, oat and barley harvests begin.

Ferns.—Spores of male-fern and bracken are ripe.

SEPTEMBER.

General Work for Autumn Months.—Trace the development of fruits from flowers, make observations of the dispersal of fruits and seeds of common herbs and trees, and collect and preserve good specimens (Chap. XVIII.). Study the plants' preparations for winter : autumn colours of leaves, phenomena of leaf-fall, etc. (Chap. X.) and the accumulation of food in twigs, etc., of trees and shrubs, and in the underground parts of perennial and biennial herbs (Chap. XII.).

Plants in flower.—Clematis, crowfoot buttercups, spearwort buttercup, monkshood ; shepherd's purse, water-cress, candytuft, stock, pansy ; white campion, pearlwort, pink, chickweed, mouse-ear chickweed ; herb Robert ; gorse, rest-harrow, clovers, bird's-foot trefoil, meadow vetch, sweat pea ; creeping cinquefoil ; water star-wort ; bryony ; water dropwort, hedge parsley ; honeysuckle ; teasel, devil's-bit scabious ; autumnal hawkbit, hawkweed, dandelion, chicory, thistles, knapweed, bur-marigold, golden-rod, groundsel, ragwort, sunflower, Michaelmas daisy, daisy, ox-eye daisy, feverfew, yarrow ; nettle-leaved bell-flower ; bell-heather, ling ; pimpernel, brook-weed ; speedwells, mullein, foxglove, toadflax, snap-dragon, musk, figwort ; water-mint, deadnettles, sage, skull-cap, self-heal, hemp nettle, wood sage ; plantains ; orache, glasswort, sea-blite ; climbing polygonum, knotgrass, dock ; hop, nettles ; Canadian water-weed ; meadow saffron ; gladiolus ; slender foxtail, annual meadow-grass.

Ash and horse chestnut **leaves** fall.

Fruits of apple, pear, plum, blackberry, and many other plants are ripe.

OCTOBER.

Plants in flower.—Shepherd's purse; pale hairy crowfoot, lesser spearwort; wild pansy; chickweed; white clover; ivy; chicory, autumnal hawkbit, bur-marigold, thistle, yarrow, daisy, corn-marigold, Michaelmas daisy; mullein, toadflax, snap-dragon, speedwells; butterwort; pimpernel; deadnettles; plantains; orache; mercury; meadow saffron; annual meadow-grass.

Most **forest-trees** shed their leaves.

Fruits of apple, pear, plum, and many other plants are ripe.

NOVEMBER.

Plants in flower.—Shepherd's purse; chickweed; ivy; daisy, groundsel; pimpernel; mullein, toadflax, snap-dragon; mercury; annual meadow-grass.

Most **forest-trees** are now leafless.

Fruits of hawthorn, rose, holly, mistletoe, etc., are ripe.

DECEMBER.

General Work for Winter Months.—Study the rhizomes, tubers, corms, bulbs, swollen roots, etc., of herbaceous perennials and biennials, noting the depth of each in the soil (Chap. XII.). Replant rhizomes, etc., in unusual positions, for examination of their resulting behaviour in spring. Grow bulbs and corms for early flowering indoors in water-glasses, fibre, etc. Learn to recognise common trees in winter by methods of branching, characters of resting buds, bark, etc., and by the leaves of evergreens (Chap. XX.). Dissect resting buds of deciduous trees

(Chap. X.). Examine the properties of different types of soil (Chap. VII.).

Flowers of shepherd's purse, daisy, annual meadow-grass and a few other plants may be found.

Fruits of mistletoe, holly, etc., are ripe.

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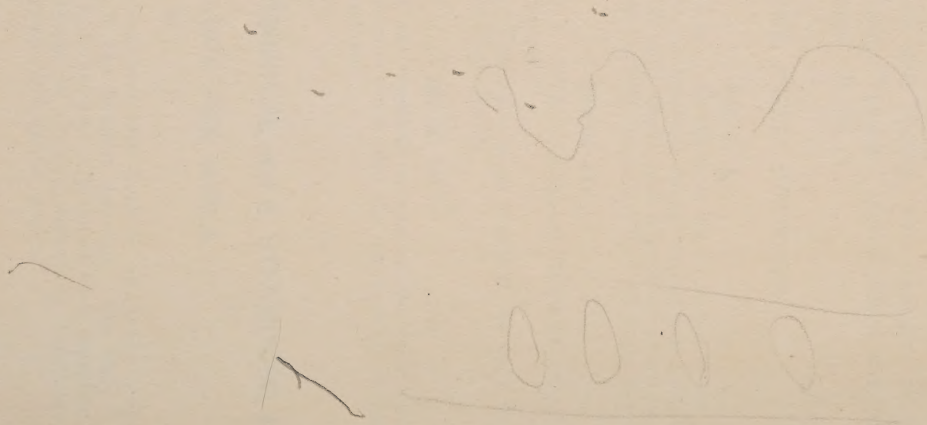

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